Vacuum Technology Division
Room 329 - Session VT-MoM

Vacuum Gauging, Outgassing and Leak Detection

Moderator: J.P. Looney, National Institute of Standards and Technology

8:40am **VT-MoM2 Data Evaluation of Gas-Analytic Mass Spectra: Special Aspects of Getter-Assisted Helium Analysis**, ***U. Langer***, *R. Dobrozemsky,* Vienna University of Technology, Austria

During the last years, a method for the decomposition of complex gas-analytic mass spectra has been developed at Research Center Seibersdorf.@footnote 1@ The method (termed Vector Mass Spectrometry - VMS) is based on the evaluation of data gathered by a quadrupole mass spectrometer (QMS) and a Bayard-Alpert gauge (BAG) during multiple spectrum scans with parameter variation. Although this method allows to analyze even complex mixtures of hydrogen and helium isotopes with accuracies in the percent range, it exhibits severe weakness if small He-amounts have to be measured in a hydrogen background. This particular problem can be overcome by selective pumping, as it has been applied in several labs for similar purposes. In a recent work we have shown that hydrogen reduction factors (i.e. relative He-enrichments) of up to about 50 can be achieved by a simple, orifice controlled SAES getter pump in combination with an additional BAG.@footnote 2@ By a mathematical trick it was possible to evaluate the data by means of the already well-established spectrum decomposition codes, based on a least-squares-fit routine. This method allows quantitative measurements of He-concentrations in the percent range in the presence of hydrogen isotopes. @FootnoteText@ @footnote 1@ R. Dobrozemsky and G.W. Schwarzinger, J. Vac. Sci. Technol. A10(4), 2661 (1992) @footnote 2@ U. Langer and R. Dobrozemsky, contributed paper, submitted to 14@super th@ International Vacuum Congress, Birmingham, UK (1998)

9:20am **VT-MoM4 Long Term Behavior of an Axial-Symmetric Transmission Gauge**, ***H. Akimichi***, *K. Takeuchi, Y. Tuzi,* ULVAC Corporation, Japan; *I. Arakawa,* Gakushuin University, Japan

An axial-symmetric transmission gauge (AT gauge) is an ionization gauge developed for the pressure measurements in ultrahigh and extreme high vacua. In the gauge, a Bessel-box type energy filter is placed between the ionizer and the ion collector to eliminate the effects of soft X-ray and electron stimulated desorption ions. The lower limit of the pressure measurement by the AT gauge is estimated to be 10 @super -12@ Pa. The sensitivity factor for hydrogen calibrated by the conductance modulation method was about 2 x 10 @super -3@ Pa @super -1@, and was constant in the pressure range from 10 @super -10@ to 10 @super -6@ Pa. We have examined the characteristics of the AT gauge such as the sensitivity factor, the outgassing rate, etc., over the period of 3200 hours. It was found that the condition of the continuous dynode type electron multiplier, which is used for the ion detection in pulse counting mode, was one of the most important factor that determine the gauge characteristics. The followings were noticed in our study: (1) the outgassing rate of the electron multiplier was higher than that of the ionizer and the energy filter, (2) the outgassing rate of the multiplier as received from the manufacturer was very high but decreased to acceptable level after a few days operation, (3) the outgassing rate of the multiplier increased after exposure to the atmospheric air but restored, (4) the temporal increment of the sensitivity factor was observed after the exposure to the atmospheric air and was assumed due to the change in the secondary electron yield of the electron multiplier, (5) the correlation between the residual current by the X-ray effect and the sensitivity factor of the gauge were observed.

9:40am **VT-MoM5 Ultra-high Vacuum Instrumentation Development Studies**, ***C. Dong***, *G.R. Myneni,* Thomas Jefferson National Accelerator Facility and Old Dominion University

Measurements of both total and partial pressure in the ultra high vacuum range are known to be limited by several effects including the x-ray limit, electron stimulated desorption, cathode evaporation and thermal and chemical effects at hot cathodes. In order to understand the contributions of these effects, ultra high vacuum instrumentation development studies are in progress at the Jefferson Lab in collaboration with Teledyne Brown Engineering-Hastings Instruments. These studies include the modification of extractor gauges and RGAs by replacing the hot filaments with Spindt field emitters. The sensitivities of the modified instruments are determined in the Jefferson Lab's vacuum gauge calibration apparatus. In this paper the sensitivities of the UHV instruments for nitrogen, helium and hydrogen with different cathode currents and for various electrode potentials are presented. In addition, the contributions of electron-stimulation desorbed ions are also measured with the help of a Watanabe ion spectroscopy gauge in an ion pump evacuated vacuum system and the results are also included here. This work supported by the U.S. DOE under contract No. DE-AC05-84ER40510

10:00am **VT-MoM6 Effect of Background Neutral Pressure on the m=1 Diocotron Mode Amplitude in a Pure Electron Plasma@footnote 1@**, *E.H. Chao, R.C. Davidson,* ***S.F. Paul***, Princeton University

The word "diocotron" was first used to describe instabilities in hollow electron columns which had shear in the angular flow velocity. These instabilities can occur in propagating nonneutral electron beams and layers and in low-voltage microwave generation devices such as magnetrons, traveling-wave tubes, and ubitrons. We use the word to generally refer to low-frequency electrostatic oscillations perpendicular to the magnetic field and have studied experimentally the mode with azimuthal mode number m=1. The diocotron mode is studied in a pure electron plasma confined in a Malmberg-Penning trap. The frequency of the mode is generally on the order of 100 kHz while the plasma frequency is on the order of 10 MHz and the electron cyclotron frequency is 100 MHz. The frequency of the m=1 diocotron mode in an infinite length column was predicted theoretically by Levy@footnote 2@, however, we find better agreement when the finite column length theories@footnote 3,4@ are used which predict an upward frequency shift from the infinite length case. The mode amplitude is affected by wall resistance as well as by the background neutral pressure. The resistive wall destabilization of the m=1 diocotron mode was predicted and experimentally verified by White@footnote 5@. Our measurements of the growth rate agree reasonably well with theoretical predictions. The m=1 diocotron mode is also predicted to be driven unstable in the presence of collisions with background neutrals@footnote 6@. However, we have found experimentally that increasing the background neutral pressure causes the amplitude of the m=1 diocotron mode to decrease as the column expands. @FootnoteText@ @footnote 1@Research supported by the Office of Naval Research. @footnote 2@R.H. Levy, Phys. Fluids 11, 920 (1968). @footnote 3@S.A. Prasad and T.M. O'Neil, Phys. Fluids 26, 665 (1983). @footnote 4@K.S. Fine and C.F. Driscoll, Phys. Plasmas 5, 601 (1998). @footnote 5@W.D. White, J.H. Malmberg, and C.F. Driscoll, Phys. Rev. Lett. 49, 1822 (1982). @footnote 6@R.C. Davidson and E.H. Chao, Phys. Plasmas 3, 3279 (1996).

10:20am **VT-MoM7 Ionization Gauge Errors at Low Pressures**, ***B.R.F. Kendall***, Elvac Laboratories **INVITED**

Factors affecting the accuracy of ionization gauge measurements at low pressures are reviewed. In hot-cathode gauges these include electron-stimulated desorption at the electron collector, forward and reverse X-Ray effects, Auger emission, outgassing, and various controller-related errors. In cold-cathode gauges they include nonlinearities below the "magnetron knee", plasma instabilities, and leakage currents. Case studies are given to illustrate many of these sources of error and their elimination. The case studies were gathered in the course of long-term stability measurements on over 30 ionization gauges at pressures ranging from 10@super-7@ to 10@super-11@ Torr. The investigation included Bayard-Alpert (both conventional and modulated), Extractor, Magnetron, Inverted Magnetron and Double Inverted Magnetron gauges. Recent measurements on Bayard-Alpert gauges with low-temperature (lanthanum boride) and cold (disordered tetrahedral carbon) emitters are also discussed. It is concluded that, with proper precautions, ten percent reproducibility in the 10@super-10@ Torr range is easily achievable with either hot-cathode or cold-cathode gauges. A combination of the two, mounted on a common vacuum flange, is particularly useful at very low pressures.

11:00am **VT-MoM9 Plasma Expansion in a Malmberg-Penning Trap as a Function of Background Pressure@footnote 1@**, ***E.H. Chao***, *R.C. Davidson, S.F. Paul,* Princeton University

Single species nonneutral plasmas have very robust confinement properties because the conservation of canonical angular momentum in a system with azimuthal symmetry provides a powerful constraint on the allowed radial positions of the particles. If no external torques act on the plasma, the plasma cannot expand radially to the wall. However, collisions with a background neutral gas will exert a torque on the rotating plasma thus allowing the mean square radius to increase. In the EDG experiment at the Princeton Plasma Physics Laboratory, a pure electron plasma is confined in a Malmberg-Penning trap and the radial density profile is measured as a function of time. The base pressure is 5*10@super -10@ Torr and purified helium is injected to pressures @>=@1*10@super -9@

Torr. The magnetic field is varied between 100 and 600 Gauss. Plasma densities up to 3*10@super 7@ cm@super -3@ are achieved and temperatures are on the order of 1 eV. This leads to a Debye length of about 1 mm while the plasma dimensions are 1-2 cm in radius and 15 cm in length. The expansion rate of the plasma in the presence of a background neutral gas has been studied theoretically by Davidson, et al.@footnote 2,3@ The expansion rates observed experimentally are faster than the theoretical prediction but the magnetic field scaling of the expansion rate is similar. In addition, using the measured radial density profiles along with a numerical code to calculate the axial density distribution, the decrease in electrostatic energy was calculated and compared with the predicted temperature rise in Ref. [3]. Finally, measurements of plasma expansion rates as a function of background gas pressure are in progress. @FootnoteText@ @footnote 1@Research supported by the Office of Naval Research. @footnote 2@R.C. Davidson and D.A. Moore, Phys. Plasmas 3 (1996) 218. @footnote 3@R.C. Davidson and E.H. Chao, Phys. Plasmas 3 (1996) 2615.

11:20am **VT-MoM10 Outgassing Measurements of Vacuum Compatible Stepper Motors*, J.W. Weed**, *R.S. Goeke, J.A. Romero,* Sandia National Laboratories

The $1.2B National Ignition Facility is currently being constructed at Lawrence Livermore National Laboratory in California. This high-power laser inertial confinement fusion device consists of 192 beams with large optical components in the vacuum environment. Over 1000 stepper motors will be used to perform automated alignment of the laser beams prior to shots. Gas load and contaminants from stepper motor outgassing can severely impact the performance and operation of the laser. We have measured the time dependent outgassing rate of "vacuum compatible" stepper motors from four different manufacturers. We have also obtained mass spectra of each motor. The results of these measurements will be presented and the impact on component performance will be discussed. Possible improvements to these commercial-off-the-shelf motors will be described. @FootnoteText@ 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

Vacuum Technology Division
Room Hall A - Session VT-MoP

Vacuum Technology Poster Session

VT-MoP1 Behavior of the Negative Collector Current in Ionization Vacuum Gauges, ***K. Kokubun***, *M. Hirata,* Electrotechnical Laboratory, Japan

In or near XHV pressure region, negative collector currents have been observed in the Extractor vacuum gauges that several times experienced a baking at 573 K for about 70 hours.@footnote 1@ It was found that the negative collector current continued to flow even when the gauge was not in operation. Authors confirmed that in these gauges a negative electromotive force of - 1 V to - 100 mV was formed in the system including the collector electrode and the gauge body, and simultaneously the insulation of the collector electrode degraded due to unknown causes. These results suggested that some new structure was formed in the gauge head system by the bakings. This conjecture was supported by measuring the temperature dependences of the negative collector current, the negative e.m.f., and the insulation resistance. These temperature dependences were remarkably different from those of a normal gauge. Especially, the insulation resistance drastically increased to about 330 K, and then abruptly decreased. This behavior was in strong contrast to that of the normal gauge. On the other hand, in the normal gauge a significantly larger positive e.m.f. was observed. But it was found that only a small positive current flowed because of the very large insulation resistance of the collector electrode. @FootnoteText@ @footnote 1@K.Kokubun and M.Hirata, J. Vac. Soc. Jpn, 40, 137(1997).

VT-MoP2 Compatibility of a Control Unit and a Sensing Coil Unit with a Rotor Ball of a Spinning Rotor Gauge, ***M. Hirata***, Electrotechnical Laboratory, Japan

A spinning rotor gauge is one of the most reliable vacuum gauge. The gauge is a noble viscosity gauge which is essential to a transfer gauge and a reference gauge in high vacuum. The gauge consists of a control unit, a sensing coil unit and a rotor ball installed in a tube. The rotor is operated frequently in a different pairing of the control unit and the sensing coil unit for convenience of transportation and use. In order to clarify the interchangeability of the electronic unit and the sensing coil unit with the rotor ball, accommodation coefficient of the rotor ball in the different pairing was measured preciously by a direct comparison with a reference spinning rotor gauge. Pressure measurements by the two gauges was simultaneously done by using a personal computer. While repeatability within 0.1% was obtained in the measurement of the relative accommodation coefficient, the rotor showed a slightly high value, 0.5%, in the coefficient in special pairings. Consideration of the experimental results in detail showed that one of seven coil units gave slightly high value in the coefficient. The coefficient did not depend on the control unit. Big tilt of the sensing coil units, about 15@degree@ from the normal vertical axis, also gave a slightly high value in the coefficient. Remagnetization changed the value of the coefficient occasionally. It seems that the coefficient depends on the mode of the rotation of the ball. A fixed pairing of the rotor with the sensing unit is preferable for a reliable pressure measurement by the gauge.

VT-MoP3 A New High-Power Ion Source Based on Magnetically Neutral Loop Discharge, ***F. Shimokawa***, NTT Opto-electronics Laboratories, Japan

We developed a new high-power ion source based on the high-density plasma formation method that is known magnetically neutral loop discharge (NLD). Our original ion source consists of three separate electromagnetic coils, as well as ion extracting grids and a quartz vessel chamber with a one-turn RF antenna coil, which is the main component of the conventional RF ion source. The three separate electromagnetic coils are located around the periphery of the chamber. The current in the middle coil flows in the opposite direction of the currents in the top and bottom coils. By using these source configurations, a magnetically enhanced plasma that is known as NLD occurs in the chamber. Our source produces a high plasma density of 10@super 11@ cm@super -3@, which is 10 times higher than that of the conventional source under a lower gas pressure of 0.1 Pa. Also, it is possible to control both the ring-like plasma diameter and the high-density plasma generation position in the chamber. As a result, we achieved the high ion current density (10 mA/cm@super 2@) at 300 V of ion extracting voltage, which is almost 10 times higher than the conventional source. Furthermore, we also obtained a high ion current uniformity of about 3% over a 6-inch diameter by using our source's plasma space controllability. A processing system that uses this new source will contribute to faster processing, excellent uniformity processing, and high quality processing for ion beam etching, ion beam deposition, and ion beam sputter deposition. Many other applications are also expected to come about from this method.

VT-MoP4 Stabilization of Long Travel - Single Bellows - Horizontal Manipulators, ***V.S. Smentkowski***, *A.L. Linsebigler,* General Electric Corporate Research and Development Center

Single bellows, long travel, horizontal manipulators are required for many experiments in surface science. Unfortunately, the gravitational force exerted on long travel - single bellows - horizontal manipulators results in stability problems including, but not limited to unwanted sample vibrations and non-reproducible sample positioning. We have designed, built, and tested a simple add on device that efficiently alleviates such problems. The device that will be described can be used with any manipulator, regardless of age. The cost to implement this device (machining and parts) is minimal.

VT-MoP5 Pressure Wave Propagation by Gas Expansion in a High Vacuum Tube, ***T. Takiya***, Hitachi Zosen Corporation, Japan*; F. Higashino,* Tokyo Noko University, Japan*; Y. Terada, A. Komura,* Hitachi Zosen Corporation, Japan

This paper describes an unsteady tube flow model which accounts for the effect of contracted flow around the entrance orifice of a tube. The sudden expansion of gas introduced into a vacuum tube is an important phenomenon, which has to be studied in relation to leakage accidents of vacuum devices. In order to predict the pressure wave propagation speed, it is necessary to model the gas expansion in a vacuum tube. So we proposed an analytical model for gas expansion in a high vacuum tube, with the aim of preventing vacuum hazards at scientific experimental facilities. Setting a very high pressure drop between the outside and inside of the vacuum tube makes the model applicable to high vacuums, although the model is based on continuous fluid dynamics. We installed an orifice on the inlet end of the tube in the model, and investigated the orifice aperture effect on the propagation velocity of pressure waves. It was found that a rarefaction wave rather than a shock wave was primarily involved in vacuum accident damage, and that orifice aperture controls pressure increase rate in the low pressure regime more sensitively than in the high vacuum regime. This study was carried out to provide necessary data in designing vacuum protection for long tube-like devices, such as the beamline for synchrotron radiation, by solving the set of basic equations that incorporates important conditions.

VT-MoP6 Measurement of Secondary Electron Yields of Copper Materials and the Surface Analysis, ***S. Kato***, *K. Kanazawa,* KEK, Japan*; N. Kitano, N. Matsuda,* Tokyo Denki University, Japan

Photoelectron instability is one of serious problems in a positron storage ring of colliding accelerators such as PEP-II and KEKB where a current of a couple of amps is stored. It occurs in a manner that the positron beam interferes with an enormous amount of secondary electrons emitted from surfaces of vacuum pipes bombarded by a large amount of photoelectrons due to synchrotron radiation. This instability considerably disturbs beam operation. In this study, secondary electron yields from copper materials where some surface treatment techniques were performed were measured to make a comparison with other materials. Target samples were prepared by three different chemical polishing techniques using a) a water solution of sulfuric acid and hydrogen peroxide, b) a water solution of citric acid and c) a) and subsequent b). These samples were treated in the same condition as the extruded copper chambers for KEKB electron-positron collider. The secondary electron yields were measured at a typical condition of a kinetic energy ranging from 0.1 keV to 2.0 keV at a normal incident and a sample temperature of 23 ° C. The residual gas pressure of the sample chamber was less than 2x10@super -7@ Pa during the measurements. In order to avoid electron beam induced contamination at the sample surface from the residual gas even so, a total dose of electrons for a measurement was limited to be 1x10@super 12@ electrons/cm@super 2@ by use of a pulsed beam. Characterization of those surfaces was also done by Auger electron spectroscopy with argon ion sputter etching. This gives information about depth profiles of atomic compositions in an altered surface layer due to the treatment discussing the interrelation between the secondary electron yields and the surface atomic compositions. The lowest maximum yield of secondary electrons of 1.05 was observed at the surface treated as (a) where the oxidized layer was found to be the most stable against a long exposure to air in contrast to the surface treated as (b).

VT-MoP7 Study of Field Emission Properties of GaN grown by ECR MBE, ***I.E. Berishev***, *O. Kameli, D. Starikov, A. Bensaoula, I. Rusakova,* University of Houston*; V.P. Ageev, M.V. Ugarov, A. Korabutov,* General Physics Institute, Russia

GaN thin films were grown by electron cyclotron resonance (ECR) molecular beam epitaxy (MBE) on Si (111) wafers. X-ray diffraction and both scanning and transmission electron microscopy were used to characterize the thin films in order to determine their crystal structure and surface morphology. The films consisted from clearly defined columns about 100 nm in diameter. Despite the large defect density, a strong room temperature photoluminescence signal was observed from these samples. The origin of this luminescence and its role on field emission will be discussed. The surface of the films exhibited random array of sharp tips at the microscopic level with about 5x109 tips/cm2 density. The field emission characteristics, voltage threshold and emission current, of these thin films were order of magnitude higher than any published data. The dependence of the emission characteristics on the doping level, substrate orientation, film thickness, and post-growth surface modification were investigated. Potential GaN/Si-based field emission devices will be discussed and preliminary results will be presented.

VT-MoP8 Outgassing Tests on Materials Used in the DIII-D Tokamak@footnote 1@, ***K. Holtrop***, *M. Hansink, A.G. Kellman,* General Atomics

In order to achieve high performance plasma discharges in the DIII-D tokamak, impurity levels must be carefully controlled. Since first wall materials can desorb volatile impurities during these discharges, it is important to characterize and control the outgassing of these materials. An outgassing chamber was built to measure the outgassing properties of various materials used in the DIII-D vessel. The results of pump-down tests performed on ATJ graphite, thin grafoil gaskets, and MGO coaxial cables will be presented. In addition, to pumpdown tests it was desired to study the behavior of the materials at temperatures up to 400°C, which is the maximum temperature to which the DIII-D vessel is baked. The station was modified to include independent heating control of the sample and a simple load-lock chamber. @FootnoteText@ @footnote 1@Work supported by the U.S. Department of Energy under Contract No. DE-AC03-89ER51114.

VT-MoP9 Simple Catalytic Cell for Restoring He Leak Detector Sensitivity on Vacuum Systems with High D@sub 2@ Backgrounds*, ***J. Busath***, *H.K. Chiu,* General Atomics

The DIII-D National Fusion Facility at General Atomics focuses on plasma physics and fusion energy science. The DIII-D tokamak is a 35 M@super 3@ toroidal vacuum vessel with over 200 ports for diagnostic instrumentation, cryogenics, microwave heating, and four large neutral beam injectors. Maintaining vacuum in the 10@super -8@ Torr range is crucial for producing high performance plasma discharges. He leak checking the DIII-D tokamak and the neutral beamlines has historically been difficult. D@sub 2@ is used as the fill gas in most plasma discharges. After plasma operations, D@sub 2@ out-gassing from the torus walls and internal beamline components can exceed 10@super -4@ Torr l/s. The mass of D@sub 2@ molecule (4.028 amu) is indistinguishable from that of the He atom (4.003 amu) to a standard mass spectrometer leak detector. High levels of D@sub 2@ reduce leak detector sensitivity and effectively mask the He trace gas signal rendering normal leak checking techniques ineffective. A simple apparatus was developed at GA to address these problems. It consists of a palladium based catalyst cell and associated valves and piping placed in series with the leak detector. This reduces the D@sub 2@ throughput by a factor greater than 10,000, restoring leak detector sensitivity. This paper will briefly discuss the development of the cell, the physical processes involved, the tests performed to quantify and optimize the processes, and the operational results at DIII-D. @FootnoteText@ *Work supported by the U.S. Department of Energy under Contract No. DE-AC03-89ER51114.

Vacuum Technology Division
Room 329 - Session VT-TuM

Molecular Drag Pumping
Moderator: J.C. Helmer, AVS Fellow

8:20am **VT-TuM1 Performance of Molecular Drag Pumping Stages in Hybrid Turbopumps**, ***M.H. Hablanian***, Varian Associates

Quantitative evaluation of molecular drag pumping action in turbopump channels allows an optimized placement of such channels among the stages of a high-compression hybrid turbine-type high-vacuum pumps. Although the drag action can be utilized in the entire range of pressures, the practical engineering considerations dictate the actual design (certain cross-section, length, parallel and series arrangement, and angular position) and placement of drag stages within the entire architecture of the pump which is to have a desired overall performance. The usual broad range of interest is between 0.1 and 100 torr but often can be more practical between 0.5 to 10 torr. Above 10 torr exit pressure, it is usually more effective to use other type of impellers. Theoretically, it may be desirable to have each stage of a hybrid turbopump of a different configuration but practical design (regarding size, ease of manufacture and assembly, and cost) necessitate some compromises. This is especially true of rotor design requirements. In addition, the choice of drag stage involves considerations of the wide range of pressure conditions in which a turbopump must function, the associated power requirements, and the crossing of various gas flow regimes. It is relatively simple to establish general guidelines for proper stage arrangements but actual design demands a complete knowledge of the performance of each individual impeller type.

8:40am **VT-TuM2 Turbodrag Pump Technologies**, ***O. Ganschow***, Schorch GmbH, Germany

Turbodrag pumps, i.e. molecular pumps with a bladed section followed by a drag section on a common shaft, have become the most popular high vacuum pump in the last 12 years, as they tolerate backing pressures approximately a hundred times larger than pure turbopumps. The paper reviews various technologies for turbodrag pumps in terms of the merits and limitations of their design principles. This covers rotor dynamics aspects, response to thermal loads, maximum rated backing pressure and throughputs, compression ration versus size as well as mechanical design considerations and potential future developments.

9:00am **VT-TuM3 Pumping Mechanism of Helical Grooved Molecular Drag Pumps**, ***T. Sawada***, *W. Sugiyama,* Akita University, Japan

The flow on a rotor of molecular drag pumps varies from viscous to slip to free molecule flow according to the decrease in pressure. As the first step, the flow through a groove facing a wall moving along the groove is analyzed. On the assumption that the flow in the groove is steady, isothermal, incompressible and laminar, the Navier-Stokes equations are simplified in the viscous and slip flow regimes and can be solved numerically with relative ease. In the free molecule flow regime, the drag (or friction) is caused by the momentum carried to a wall-piece by gas molecules colliding with the wall-piece, and the drag must be equated to the force exerted by the pressure on the two cross-sections sandwiching the wall-piece. The weighted linear combination of the two equations for slip and free molecule flows can describe the flow through the three flow regimes. The flow in ridges which leads a leak is treated in the similar way to the flow in grooves. Then, the flows in grooves and ridges hitherto treated separately are connected by the continuity condition of mass flow rate normal to the groove-ridge interface. The pressure gradient which is discontinuous at the groove-ridge interface is smoothed by Boon and Tal's "Narrow groove theory ". The pressure difference or the pressure ratio across the pump is obtained from the relationship between the smoothed pressure gradient and the axial mass flow rate derived above. The calculated results suggest that the radial clearance can be enlarged by factors of 20-100, compared with that of a conventional Holweck-type pump.

9:20am **VT-TuM4 Measurements Illustrating the Importance of Desorption and Molecular Residence Times on the Molecular Drag Process**, ***A.D. Chew***, *R.A. Abreu, I. Creaye,* BOC Edwards, United Kingdom

Knowledge of the molecular residence time is a fundamental factor in the understanding of molecule-surface interactions and has special relevance in the analysis of the molecular drag process. In this paper we describe experiments based on a technique originally devised by Holst and Clausing.@footnote 1@ In this technique molecules are beamed onto a variable high speed rotating disc and the point of desorption is measured. This in principle provides a means for the direct determination of the residence time. Preliminary results for various gas-surface combinations including nitrogen, helium, oxygen, krypton and perfluorocarbons on aluminium are presented. The method was further exploited to investigate the effect of surface speed on the desorption flux distribution, and to give insight into the mechanism of the molecular drag process for gases of different molecular mass. The possible application of this phenomenon to gas separation is discussed. @FootnoteText@ @footnote 1@G Holst and P Clausing, Physica 6, 48 (1926)

9:40am **VT-TuM5 Improved Design of a Multi-Groove Vacuum Pump Compressing Directly to the Air**, *E.S. Valamontes,* ***S.E. Valamontes***, *C.N. Panos,* Technological and Educational Institute of Athens, Greece

For a multi-groove vacuum pump the shortening of its length, during its function, is related to the increase of the velocity of molecules of the pumping gas. We are trying to achieve it without increasing the number of the turns, which leads to the increase of the velocity, but by using some new ideas. We study the exact behavior of the coefficient of internal viscosity by introducing a disc with blades in the pump which indirectly leads to the desirable shortening of its length and finally to have a pump compressing directly to air. The appropriate shape of the disk and its design are the main problems of the present work.

10:00am **VT-TuM6 Matching of Turbine Stages to a Drag Stage under Viscous Flow Conditions**, *Ch. Beyer, H. Englaender,* ***P.J. Klingner***, Leybold Vacuum GmbH, Germany

The design of the adapter part between the turbo molecular part and the drag stage of a compound pump is decisive for - the high vacuum performance (a) the fore vacuum pressure tolerances (b) the manufacturing costs and (c) the degree of compactness of this pump (d) especially in process applications under viscous or molecular-viscous transition flow conditions. The authors present approaches for the layout of turbo rotor stages at viscous flow (Leybold Advanced Technology). Operation diagrams illustrate the combination of turbo molecular and drag stages as part of pump optimization; measurement data give first informations about the influence of specially designed filling stages on the adapter efficiency.

10:20am **VT-TuM7 Flow Investigation of Siegbahn Pump by CFD Methodology**, ***H.-P. Cheng***, Precision Instrument & Development Center, Tawain. Read by J. Helmer, with historical figures by L. Westerberg.

The maximum flow through turbomolecular pumps or turbodrag pumps is limited by the maximum rotor temperature resulting from gas friction. Further, a variety of applications, especially in the semiconductor industry, require a high pumping speed in the 1 - 100 mtorr pressure range. Main subject of the presentation is the special design of the drag section of a turbodrag pump and the resulting improvements related to the features: maximum gas flow and high pumping speed in the 1 - 100 mtorr pressure range.

10:40am **VT-TuM8 Performance of a Peripheral Drag Pump**, ***T. Ohbayashi***, Osaka Vacuum, Ltd., Japan; *T. Sawada,* Akita University, Japan

This is a theoretical and experimental study of a peripheral drag pump. It has a peripheral pumping channel and a gas inlet and outlet which are separated by a "stripper", this is similar to a Gaede's drag pump. In that type of pump, a pumping channel comprises an annular groove and a chamber wall. In the pump in this study, two pumping channels which work in parallel comprise a rotating disk and two annular stators. This modification keeps the leak small with a relatively large clearance between the rotor and the stator. The performance of the peripheral drag pump is determined by the flow through the pumping channel, the "carry back", the leak in the "stripper" region, and the leak in the clearance between the rotor and the stator. In the theoretical calculations, the flow through the pumping channel is evaluated as Poiseuille flow and Couette flow through rectangular channels and the flow in the stripper region and in the clearance are evaluated as Poiseuille flow and Couette flow between parallel plates. Experiments were carried out on the peripheral drag pump of a single stage in a pressure range of 3 - 1300 Pa for air and 9 - 1200 Pa for hydrogen. The theoretical predictions agreed with the experimental results.

11:00am **VT-TuM9 Development of New Generation Turbo Molecular Pump*, Y. Maejima**, C. Urano,* Seiko Seiki, Japan

300mm wafer process requires extremely high process gas flow. Therefore, pumping requirements for vacuum pumps have increased up to 3,000 l/s. However, large pumps have disadvantages such as heavy weight, effect in case of failure. Our solution and concept for the new generation vacuum pump is to develop a 2,000 l/s dimension pump with higher performance than a 3,000 l/s pump at process pressure range. (from 1 Pa to 3 Pa) To accomplish this development, our target was to maintain pumping performance down to 5 Pa. We have simulated the influence of turbine blade parameter (blade length, dimension, shape) for maximum gas flow performance.

11:20am **VT-TuM10 Power Dissipation in Turbomoleculars Pumps at High Pressure*, R. Cerruti**, M. Spagnol, J.C. Helmer,* Varian VPT, Italy

The operating range of Turbopumps is being extended to higher pressures as a consequence of many demanding applications. Varian VPT has specialized in the design of Gaede stages for extending the operating pressure of the pump. In this paper, another important design aspect of a Gaede stage is identified and analyzed: the power consumption in viscous flow conditions Starting form the analysis of the pressure distribution into a single Gaede stage, already presented in a previous paper, a transitional power consumption model is derived. The model allows to predict the power consumption of a single Gaede stage as a function of the pumping channel dimensions and clearances, the rotational speed, the nature of the gas pumped and the operating pressure. The model is based on three main assumptions: 1. the pressure distribution along the channel satisfy a diffusion viscous model at zero net gas flow 2. the gas flow boundary layer across channel is derived from a simple viscous model 3. the gas viscosity obeys a transition expression valid for the pumping channel geometry Results are compared with the experimental data provided by different single Gaede stages, with different dimensions, at different speed and operating pressure. The behavior of the model with different pump stage clearances is analysed and results are compared with the experimental evidence. A useful use of the model is in the optimization of the design of multistage Gaede pumps.

Vacuum Technology Division
Room 329 - Session VT-TuA

Drag Pumping and Transition Flow Phenomena

Moderator: T. Sawada, Akita University, Japan

2:00pm **VT-TuA1 How Gaede Was Forgotten*, J.C. Helmer,*** AVS Fellow

In 1913 W. Gaede published a theory of the molecular drag pump, including data from an experimental pump which bears his name. To the author's knowledge, all reviews of this subject have reproduced Gaede's theory without qualification. However Gaede himself noted that for molecular flow his theory is off by orders of magnitude. This discrepancy was forgotten by subsequent authors. At Varian SpA, it was found in both molecular and viscous flow, that Gaede's model may be corrected with the addition of an active "pumping" leak at the end of the channel, for which there is an exact and simple theory. Design of the channel to the leak-limited compression ratio is specified by a "golden rule". We also proved that a differential velocity between adjacent channel surfaces is not necessary for the pumping action. Gaede's later designs suggest that he knew this. The modern Gaede model can now be applied to the pumping action of the Holweck pump in the direction of surface drag. What Gaede did not discuss is the possible influence of Bernoulli and inertial effects at high pressure. We will conclude with a discussion of the importance of inertial effects in the Gaede pump model.

3:20pm **VT-TuA5 Direct Simulation Monte-Carlo Method for Molecular and Transitional Flow Regimes in Vacuum Components*, O. Boulon,*** *R. Mathes,* Alcatel High Vacuum, France*; J.-P. Thibault,* LEGI-IMG, France

With the active development of semiconductor fabrication technology, dilute gas flow phenomena are recently attracting attention. The gas flow through a vacuum component can be continuous, transitional or molecular depending on the pressure range and geometries involved. The present work proposes a method for simulating molecular and transitional flows using the direct simulation Monte-Carlo method (DSMC), first developed by Bird.@footnote 1@ DSMC codes directly simulate nature by moving computational particles through space. The computational model takes as data combinations of pressures, temperature of gas, type of gas and geometry of the vacuum components. The results of the computations are gasflow, local velocities, and molecular density distribution. The model was first tested and validated for several simples geometries such as circular and rectangular finite length tubes with static and moving walls, for different flow conditions. The molecular flow "aspect" is checked by comparing results with existing analytical values in the literature. The model was found to agree well with other published results in this field. From molecular to transitional flow, velocity profiles show the importance of viscosity effect for the different Knudsen numbers varying from 40 to 0.04 (pressure range from 5.e-03 to 5 Pa). The flow rate obtained for the smallest Knudsen number is close to the viscous value corresponding to Poiseuille's law. The aim of the study is to develop a model that we can adapt to more complicated geometries of vacuum components such as stage of turbomolecular or molecular pump and to predict the flow rate from molecular to transition flow regimes. @FootnoteText@ @footnote 1@G.A. Bird "Molecular gas dynamics and the direct simulation of gas flows". Oxford Science Publications, Clarendon Press, 1994.

3:40pm **VT-TuA6 Viscosity and Slip Measurements with a Modified Spinning Rotor Gauge*, J.A. Bentz,*** *S.K. Loyalka, R.V. Tompson,* University of Missouri, Columbia

The spinning rotor gauge (SRG) has become a practical method in determining the coefficients of viscosity, velocity slip, and tangential momentum accommodation for rarefied gases with a high degree of accuracy. In previous papers, we discussed the use of the SRG for measurement of these quantities for noble gases (He, Ar, and Kr), polyatomic gases (N@sub2@ and CH@sub4@), and binary gas mixtures (He-Ar, He-N@sub2@, and He-Ne). In all of our previous experiments, we considered the axis of sphere rotation parallel to the axis of the cylindrical tube inside which the sphere rotates (in the MKS gauge, the sphere rotation axis is normal to the tube axis). Based on these calculations, we suggested how the results could be used for measurements of viscosity, the velocity slip and the tangential momentum accommodation coefficients. However, the theory used for our calculations required a sphere spinning co-axially to the cylinder. We have modified our experimental apparatus to achieve this geometry. A selection of experimental measurements for He and Ar gases which have been made with a modified spinning rotor gauge are reported. All of the experiments were conducted in the slip regime. Theoretical results from a previous paper on the SRG are used to extract values of the viscosity, the velocity slip coefficient and tangential accommodation coefficient from the experimentally obtained data for both gases. These are compared with previous experimental results. The measured viscosities are in excellent agreement with existing literature values.

4:00pm **VT-TuA7 Two Point Calibration Scheme for the Linearization of the Spinning Rotor Gauge at High Pressures*, J. Setina,*** Fotona d.d., Slovenia

Commercial spinning rotor gages (SRGs) use a special linearization procedures to compensate for a vanishing pressure dependence of the rotor deceleration rate in the transition regime from 0.1 to 100 Pa. These procedures have been found to have large errors above 10 Pa,@footnote 1@ but can be significantly improved. An extensive set of experimental data of rotor deceleration rate versus gas pressure up to 130Pa was acquired. A group of six SRGs and four gases (N@sub 2@, Ar, He and H@sub 2@) were used in the study. Temperature measurements where also included to account for heating effects. The data shows that the differences between rotor/thimble combinations are large enough to cause differences of several % if one uses the linearization functions currently in use without adjustable parameters. To get the best accuracy, one parameter is left in our linearization procedure to be determined by calibration. We call it the Knudsen length of the rotor/thimble assembly. This is the second calibration constant of SRG that needs to be determined for accurate pressure measurements above 1Pa. The method to determine the second calibration constant at 100Pa will be proposed. The first calibration constant is the already well-known rotor accommodation coefficient and is determined in molecular regime below 0.01Pa. Achievable accuracy of the new linearization procedure with the two calibration parameters is better than 1% over the entire range from molecular regime up to 130Pa. The effect of thimble temperature on this linearization procedure will also be discussed. @FootnoteText@ @footnote 1@J.Setina and J.P.Looney, Vacuum, 44,1993, p.577

4:20pm **VT-TuA8 Design and Characterization of High Capacity NEG Pumps Embedded Inside the Interaction Regions of DA@PHI@NE*, R. Giannantonio,*** *P. Manini, F. Mazza, R.M. Caloi, D. Dominoni,* SAES Getters S.p.A., Italy*; A. Clozza,* Infn Lnf, Italy*; L. Zanin,* DG Technology Service, Italy

The DA@PHI@NE @PHI@-factory is a twin ring 510 MeV e@super +@e@super -@ collider facility under commissioning at INFN-LNF in Frascati. With a stored beam current of 5.3 A, a mean pressure of 1*10@super -9@ Torr is required in each ring. To cope with a total gas load, mainly consisting of CO, of 1.2*10@super -4@ Torr*l*s@super -1@ for each of the electron/positron ring, sputter ion pumps and titanium sublimation pumps with a total pumping speed of about 1.2*10@super 5@ l*s@super -1@ were installed on each ring. For the KLOE interaction region, where a mean pressure of the order of 1*10@super -10@ Torr is required, an embedded Non Evaporable Getter (NEG) pump with a CapaciTorr@super TM@-type structure was chosen mainly because of the unavailability of room for the installation of lumped pumps and to take advantage of the utmost sorption capability of the NEG pump for CO in the UHV operating conditions of the machine. A NEG pumping system of the kind discussed in this paper seemed to be particularly suitable for the KLOE experiment, where limited servicing and high reliability is required. In this paper we report on pumping speed measurements performed on a first pump prototype, fitted with St-172 NEG alloy, featuring sorption rates as high as 5*10@super 3@ l*s@super -1@. We also discuss on the design and characteristics of the final pump version, where St-185 NEG alloy is used. Computer simulations of the pressure distribution inside the interaction beam pipe are also shown, demonstrating the effectiveness of the selected technical solutions.

4:40pm **VT-TuA9 Hydrogen Pumping Simulation for Cryopumps*, S. Nesterov, J. Vasiliev,*** Moscow Power Engineering Institute, Russia*; **L.C. Wagner**, M. Boiarski,* IGC-APD Cryogenics Inc.

Cryopumps are an effective way to create clean, high vacuum. When designing a new cryopump, it is desirable to have some tool to predict cryopump performance for the different cryopanel geometries that are being considered. Monte Carlo simulation is a method that has been used for evaluating the pumping speed of a cryopump when it has not yet accumulated any gas. The simulation of hydrogen pumping has its own challenges due to the typical location of the hydrogen pumping sites and interactions with other gases. As gases accumulate on the pumping surfaces, the passageways for hydrogen gas are restricted. This paper

describes the work that was done, using Monte Carlo simulation, to study the hydrogen pumping speed and capacity of a typical cryopump as it accumulates hydrogen, water and argon. The hydrogen pumping speed is predicted as a function of the amount of other gases that have been accumulated.

Vacuum Technology Division
Room 329 - Session VT-WeM

Vacuum Microelectronics

Moderator: J.W. Weed, Sandia National Laboratories

9:00am **VT-WeM3 Electron Beam Degradation of Sulfide-Based Thin Film Phosphors for Field Emission Flat Panel Displays**, ***B.L. Abrams,*** University of Florida, Gainesville*; T.A. Trottier,* Motorola*; H.C. Swart,* University of the Orange Free State, Republic of South Africa*; E.S. Lambers, P.H. Holloway,* University of Florida, Gainesville

The change in cathodoluminescence (CL) brightness and changes in surface chemistry of the thin film phosphor, SrS:Ce, have been investigated using a scanning Auger electron spectrometer and an Orial optical spectrometer. The data for SrS:Ce were compared to ZnS:Cu,Cl,Au and Y@sub 2@O@sub 2@S:Eu powders all collected in a stainless steel UHV chamber with gas pressures of 10@super -6@ Torr O@sub 2@. In the presence of a 2kV primary electron beam, the amounts of C and S on the surface decreased while the oxygen concentration increased. As a result, ZnO, Y@sub 2@O@sub 3@ and preumably SrO@sub x@ formed. This change in surface chemistry coincided with a decrease in CL brightness. SrS degraded much faster than ZnS of Y@sub 2@O@sub 2@S. The model for this degradatin process suggests that the primary electron beam dissociated physisorbed molecules to reactive atomic species. These atomic species reacted with surface S and C, carrying them away and leaving behind an increasingly more impenetrable layer. Threshold voltage experiments were conducted to reveal where it becomes possible to measure the CL. This threshold voltage should be affected by the oxide layer discussed above. The implications for vacuums in an FED FPD will be discussed. This work was supported by Darpa grant MDA 972-93-1-0030 through the Phosphor Technology Center of Excellence

9:20am **VT-WeM4 Current Status of Field Emission Displays (FED's)***, **B.E. Gnade,*** Defense Advanced Research Projects Agency **INVITED**

Over 12 years have passed since the first field emission display (FED) prototype was built by LETI, France; this was a 5Ó diagonal, 1/4 VGA monochrome screen. At present, commercially available screens of similar design are beginning to emerge. These displays, manufactured by PixTech Inc., are based on a low-anode-voltage (<1kV) concept and are geared primarily for instrumentation applications. However, FED screens of superior image quality, including brightness and color purity, must be produced in order to challenge AMLCDs and ultimately the CRT beyond niche applications. To this end, Motorola adopted a high-anode-voltage approach to FED design that results in full-color, sun-light readable FED prototypes. In my presentation, I will address some of the challenges faced in producing a high-anode-voltage FED. In addition, I will describe some of the ongoing efforts at Motorola to produce still more readily affordable and reliable displays, such as those based on carbon cathodes.

10:00am **VT-WeM6 Thin Film and Powder Phosphors for Field Emission Flat Panel Displays***, **P.H. Holloway**, S. Jones, T.A. Trottier, J. Sebastian, B.L. Abrams, J. Thomes,* University of Florida, Gainesville*; H.C. Swart,* University of the Orange Free State, Republic of South Africa **INVITED**

Field emission displays (FEDs) are now available in the market place as monochrome product, and full color displays are available for engineering evaluation. Critical to the success of the full color display will be the performance and lifetime of the red, green and blue phosphors. The effects of operating voltage, current density, residual vacuum and phosphor, tip interactions will be discussed. The critical parameters are the phosphor brightness, efficiency, and lifetime, which are impacted by numerous factors. Reduced saturation effects have been demonstrated in FED phosphors by reducing the luminescent lifetime so that luminescent centers may be excited multiple times during one writing cycle. Charging of phosphors, especially at low voltages, has been studied and new models developed which may lead to better control through processing. Considerable progress has been achieved in understanding the limited lifetime and the phosphor/tip interaction. The surface chemistry of the phosphors is critical to brightness and efficiency, and electron beam stimulated surface chemical reactions with residual vacuum gases have been shown to dominate the evolution of surface chemistry. This is particulary true for sulfur-containing phosphors, but also true for oxide-based phosphors as well. This mechanism will be reviewed in detail, and the effects on FED phosphors will be discussed.

10:40am **VT-WeM8 A Poor Vacuum Tolerant, Low-Voltage, Scalable, Thin-Film-Edge Dispenser Field Emitter Array***, **D.S.Y. Hsu,** H.F. Gray,* Naval Research Laboratory **INVITED**

A new low-voltage, poor-vacuum-tolerant, area-scalable, field emitter array (FEA) electron source has been developed for field emitter displays (FEDs). The new FEA cell has a horizontal gate to minimize capacitance and a vertically oriented multi-layer thin-film-edge dispenser field emitter. This multilayer thin-film emitter is made with alternating high work function and low work function metal thin films with a total thickness in the range of 60-75 nm. The FEA cell aperture diameter is about 400 nm and the height of the emitter is about 0.5 micrometers. Spacing between the gate aperture edge and the emitter film is about 75-90 nm. This new FEA, based on chemical beam deposition, is fundamentally self aligned and should not depend on high resolution lithography. All dimensions are totally independent; that is, the FEA cell aperture diameter, spacing between gate edge and emitter, emitter height, insulator thickness, gate thickness, number of multi-layers, thickness of multi-layers, etc. can be independently designed without effecting the other dimensions. The number of processing steps is less than 1/3 the number required for other FEAs. We have measured single FEA cell emission of about 5-10 microamps using an extraction voltage of 60 volts and about 10 nanoamps with 30 volts. We have also observed no emission degradation after repeated cycling from 10@super -8@ to 10@super -6@ torr of room air. No activation procedures are required and exposure to atmosphere has no measurable effect.

11:20am **VT-WeM10 Diamond Coated Silicon Field Emitter Array***, S. Albin, **W. Fu,*** Old Dominion University*; G.R. Myneni,* Thomas Jefferson National Accelerator Facility

Diamond coated silicon tip arrays, with and without a self-aligned gate, were fabricated and their I-V characteristics were measured. Sharp silicon tips were prepared by a wet etching technique. For samples without the gate, the silicon array was selectively nucleated at the tip region using ultrasonic agitation in a 10-nm diamond suspension. CVD diamond films were grown uniformly on the tips with a negative bias on the substrate to enhance the diamond growth. The arrays were tested for current emission under a vacuum of 10@super -6@ torr. A piece of polished silicon was used as anode with a 2-@micron@ thermal oxide spacer. An emission current of 50 @mu@A was obtained at 5 V from an array of 400 tips. The I-V curve of the diamond coated silicon arrays showed typical diode characteristic under forward and reverse bias. To fabricate the self-aligned gate structure, 1-@micron@ thermal oxide was grown on the etched samples followed by deposition of 0.2 @micron@ tungsten as a gate metal using RF sputtering. After planarization by etch back, the exposed gate metal and oxide were removed from the tips. Diamond films were grown selectively on the silicon tips. A copper anode was placed 200 @micron@ away from the array surface with an applied voltage of 400 V. The turn-on gate voltage was found to be 40 V for the gate aperture of about 1.5 @micron@. An emission current of 3 @mu@A was obtained from an array of 400 tips at a gate voltage of 80 V. Our technique shows the potential for development of diamond based low voltage vacuum electronic devices and field emission based micro sensors.

11:40am **VT-WeM11 Field Emission Characteristics of SiC Capped Si Tip Array by Ion Beam Synthesis***, D. Chen, **W.Y. Cheung**, S.P. Wong, Y.M. Fung,* The Chinese University of Hong Kong, Hong Kong*; J.B. Xu,* The Chinese University of Hong Kong, China*; I.H. Wilson,* The Chinese University of Hong Kong, Hong Kong*; R.W.M. Kwok,* The Chinese University of Hong Kong, China

High dose carbon implantation into Si tip array and Si wafer using a high beam current density Metal Vapor Vacuum Arc ion source were performed to synthesis SiC/Si heterostructure tip array. Silicon tip array were prepared by anisotropic chemical etching. An implantation energy of 35keV was used to a dose of 1.0*10@super18@ ions/cm@super2@ were performed and subsequent annealing in argon ambient at 1200@supero@C for various time were performed to form SiC capping layer. Scanning Electron Microscopy (SEM) revealed the Si are sharp and uniformly arranged. X-ray photoelectron showed that a thin surface SiC layer has been formed. Electron Field Emission characteristics have been measured using a diode structure by using a spacer in an ultra-high vacuum chamber with a base pressure better than 2*10@super-8@ torr. Results shown that electron emission properties depend on the processes conditions of the these samples. Typical turn-on field and emission current density are about 2.5 V/mm and 1mA/cm@super2@, respectively. These results were compared with that of planar structure prepared by ion implantation into Si wafer.

The dependence of the electron emission mechanism on the surface morphology and the structure of the samples will be presented and discussed. This work is supported in part by the Research Grants Council of Hong Kong (Ref. No. CUHK513/95E)

Vacuum Technology Division
Room 329 - Session VT-WeA

Vacuum Systems and Components

Moderator: J.L. Provo, Sandia National Laboratories

2:00pm **VT-WeA1 Design and Installation of a Low Particulate, Ultra-High Vacuum System for a High Power Free Electron Laser**, ***H.F. Dylla***, *G. Biallas, L.A. Dillon-Townes, E. Feldl, G.R. Myneni, J. Parkinson, J. Preble, S. Williams, M. Wiseman,* Jefferson Lab

A high-average power (kW) infrared free electron laser (FEL) is currently being commissioned for the Jefferson Lab FEL User Facility. The IR FEL is driven by a unique superconducting RF linac which is recirculated to recover electron beam power that is not radiated in the FEL. The design and installation of the vacuum system for the FEL involved particular attention to minimizing particulate contamination which could cause problems with the superconducting acceleration cavities and the high power FEL optics. Particulate contamination levels of all vacuum components were monitored during the cleaning process using laser scattering. Cleaning, transport and installation procedures were developed to minimize the contamination of the complete system. We will summarize a data base we compiled of particulate contamination levels of the various components installed in the FEL vacuum system. This work supported by the U.S. DOE Contract No. DE-AC05-84-40150, the Office of Naval Research, Commonwealth of Virginia and the Laser Processing Consortium.

2:20pm **VT-WeA2 Vacuum Instrumentation and Control System for the Relativistic Heavy Ion Collider**, ***L.A. Smart***, Brookhaven National Laboratory*; R.C. Lee, D. Weiss, D. Zigrosser,* Brookhaven National Laboratory, US

The Relativistic Heavy Ion Collider (RHIC) Project is a nuclear physics research accelerator entering its final year of construction, with beam circulation scheduled for March 1999. To achieve beam emittance growth and lifetime, the vacuum in the two concentric rings must be at specified levels, and the sector valves isolating the cryogenic beam lines from those at room temperature must be open. The RHIC vacuum instrumentation and control (I&C) system performs multiple functions, the first of which is operating the sector valves with input from over one thousand gauges and pumps distributed around the 3.8 km circumference of the accelerator rings. Other vacuum system control functions include operating all gauges, pumps and valves from remote locations, supplying data for beam permits, data logging, and display of vacuum system parameters. Vacuum gauging includes inverted magnetron and convection-Pirani total pressure gauges, and partial pressure analyzers with faraday cup and electron multiplier detectors. Pumps on the high and ultrahigh vacuum chambers include sputter-ion, turbo molecular, and titanium sublimation pumps. Multi-drop serial communication networks are used to transfer pressure readings from gauge and turbo molecular pump controllers 300 m distant to distributed programmable logic controllers, which form the heart of the vacuum system control. This paper describes the architecture and implementation of the RHIC vacuum I&C system from the pumps and gauges to the remote operator interfaces used to control them.

2:40pm **VT-WeA3 An Ultra-High Vacuum System for Hydriding Rare Earth Metal Films**, ***S.J. Black***, *F.J. Steinkruger, C.W. Walthers,* Los Alamos National Laboratory **INVITED**

Los Alamos National Laboratory has designed, fabricated, assembled and tested a state-of-the-art vacuum system for the hydriding of reactive rare earth metal films. The application of this system is dihydriding 5000Å erbium films on molybdenum substrates for neutron tubes. Neutron tubes are a major component of neutron generators, which are used in modern nuclear weapons. The system is capable of achieving pressures in the 10@super -10@ torr range. Such pressures are desirable in order to reduce contaminant gas species (which would otherwise compete with the hydriding reaction), to the parts per billion level. The vacuum is provided by oil-free turbomolecular/molecular drag pumps. Rough pumping is provided by a scroll pump backed by a metal bellows pump. In order to achieve these low pressures, measures were taken in the design and operation of the system. In order to reduce outgassing within the system, we eliminated all organic material within the system through the use of all-metal valves. All fittings are either welded or rely on metal O-rings. Passivation of the vacuum system interior surfaces was performed to reduce condensation of oxygen and water on the stainless steel surfaces. Other materials used within the vacuum system (film substrates, fixtures, and radiation shields) are made of molybdenum which is extensively cleaned prior to use. The loader system is capable of heating the films to 700°C while under vacuum, and continuing to maintain those temperatures after adding several hundred torr of hydrogen isotopes or inert purge gases to the system. Since the vacuum system is opened each time films are either loaded or removed from the vacuum chamber, the apparatus is installed within an inert (nitrogen) glovebox. Remote operation of the system is made possible through the use of pneumatically-actuated valves. The system is heavily instrumented in order to achieve tight process control. Two residual gas analyzers (RGA's) are used to determine the chemical composition of species within the system during evacuation. Details of the hardware design will be presented as well as performance data.

3:20pm **VT-WeA5 Thermal Stability and Sealing Performance of Perfluoroelastomer Seals as a Function of Crosslinking Chemistry**, ***M.J. Heller***, *J.M. Legare, S. Wang, S. Fukuhara,* DuPont Dow Elastomers

Perfluoroelastomer (e.g. Kalrez, Chemraz, etc.), fluoroelastomer (e.g. Viton, etc.) and silicone parts are widely used in sealing applications for semiconductor wafer processing equipment. More specifically, they are often used as O-ring seals in dry chemical process equipment (e.g., Plasma Etchers, Ashers, Diffusion Furnaces, CVD, LPCVD, RTP and Lamp Anneal, etc.). Many of these seals are required to function at process temperatures ranging from 200 - 300°C and in some cases higher. The ability of an elastomer to resist thermal degradation has a significant impact on its ability to function effectively as a seal over time. This paper evaluates and compares the relative long term sealing performance of perfluoroelastomers having different crosslinking chemistries and other typically specified high performance elastomers. Long term compression set and seal force retention data is presented, including a discussion of the different test methods and their relative value in predicting seal performance at elevated temperatures. In addition, air heat aging data for other typically measured physical properties (i.e., Shore A Hardness, 100% Modulus, Tensile Strength at Break, Elongation at Break, % Weight Loss) is also presented and discussed. Results indicate perfluoroelastomers seals have the best long-term compression set characteristics and retain the highest percentage of their original sealing force over time. In addition, data shows perfluoroelastomers having an organo-metallic cross-linking system are the most thermally stable and exhibit the best long term seal performance at elevated temperatures versus those having an organic-peroxide cross-linking system. Finally, because the test conditions best reflect static o-ring seal service conditions, analysis of seal force retention test results provide a more realistic comparison of thermal stability and its relative impact on sealing performance.

3:40pm **VT-WeA6 Vacuum Insulation, 100 years of Cryogenics, and Clean Ultra High Vacuum**, ***G.R. Myneni***, Thomas Jefferson National Accelerator Facility

Sir James Dewar invented vacuum insulation (~ 1872) for improving high temperature calorimetry. He improved the vacuum in his double walled containers with charcoal for cryogenics use. He further enhanced the effectiveness of his dewars by silvering the inner walls. Dewar liquefied hydrogen for the first time on May 10, 1898 and Kammerlingh Onnes won the race of liquefying helium by 1908. Onnes discovered superconductivity in the year 1911. The heat capacity of materials at cryogenic temperatures provided some of the earliest scientific validation of quantum theory. The American space program gave the impetus for developing the multi layer insulation (MLI) to reduce the weight of launch vehicles and spacecraft. Cryopumping is providing clean ultra high vacuum in many high tech systems including semiconductor fabs and accelerators. Jefferson Lab's accelerator (CEBAF) has three independent vacuum systems (vacuum insulation, wave guide vacuum and beam line vacuum) and all of them benefit from cryopumping. The beam line vacuum inside the CEBAF cryomodules is extremely low. Diamond field emitter based extreme high vacuum instrumentation is being developed presently to measure such low pressures. High efficiency dewars are also being used in high tech medical diagnostic systems such as magnetic source imaging (MSI). These historic and present developments will be reviewed in this paper on the occasion of the centenary of the liquefaction of hydrogen by Sir James Dewar. This work supported by the U.S. DOE under contract No. DE-AC05-84ER40510.

4:00pm **VT-WeA7 Method for Measuring Deuterium in Erbium Deuteride Films**, ***J.R. Brangan***, *S.M. Thornberg, M.R. Keenan,* Sandia National Laboratories **INVITED**

Determining the quantity of deuterium in an erbium deuteride (ErD@sub 2@) film is essential for assessing the quality of the hydriding process but is a challenging measurement to make. First, the ideal gas law cannot be

applied directly due to high temperature (950@super o@ C) and low temperature (25@super o@ C) regions in the same manifold. Additionally, the metal hydride does not release all of the deuterium rapidly upon heating and metal evaporation occurs during extended heating periods. Therefore, the method developed must provide a means to compensate for temperature inhomogeneities and the amount of deuterium retained in the metal film while heating for a minimal duration. This paper presents two thermal desorption methods used to evaluate the kinetics and equilibria of the deuterium desorption process at high temperatures (950@super o@ C). Of primary concern is the evaluation of the quantity of deuterium remaining in these films at the high temperature. A multiple volume expansion technique provided insight into the kinetics of the deuterium evolution and metal evaporation from the film. Finally a repeated pump-down approach yielded data that indicated approximately 10% of the deuterium is retained in the metal film at 950@super o@ C and approximately 1 Torr pressure. When the total moles of deuterium determined by this method were divided by the moles of erbium determined by ICP/AES, nearly stochiometric values of 2:1 were obtained for several erbium dideuteride films. Although this work presents data for erbium and deuterium, these methods are applicable to other metal hydrides as well. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DEAC04-94AL85000.

4:40pm **VT-WeA9 Characterization of Aluminum Materials Focusing Electron Stimulated Gas Desorption and Its Surface Analysis in Surface Treatment Techniques*, M. Nishiwaki,*** *S. Kato,* KEK, Japan

In a hot vacuum environment such as a particle accelerator, gas desorption from a vacuum surface during the operation seriously affects the stability, the quality and the lifetime of the electron or ion beam. In order to adopt vacuum materials and surface treatment techniques to hot vacuum, reported data of thermal outgassing from vacuum surface do not always give established indication for outgassing due to particle irradiation. Therefore it is very important to evaluate gas desorption of the materials and the treatment techniques using energetic particle bombardment. We focused on measurement of electron stimulated gas desorption from aluminum materials mainly and its surface analysis in this study. Four different surface treatment techniques for aluminum materials were carried out to make comparison, that is, machining with oil lubricant and subsequent degreasing (OL), machining with a liquid jet of ethyl alcohol (EL), machining in a gas mixture of argon and oxygen (EX) and machining with corona discharges in the same gas mixture (EXP). In order to measure electron stimulated desorption rates from those surfaces quantitatively, a throughput method was used with a pressure calibrated RGA. The base pressure of the sample chamber was in an order of 10@super -7@ Pa. Electrons from an e-gun were irradiated against the samples at a typical condition of a kinetic energy of 1.5 keV, a current density of 10@super -3@ A/cm@super 2@ at a normal incident and a sample temperature of 27 ° C. Surface characterization of those samples was also done by use of Auger electron spectroscopy with sputter etching. This gives information about depth profiles of atomic compositions in an altered surface layer due to the treatment discussing the relation between the electron stimulated desorption rates and the surface atomic compositions.

Applied Surface Science Division
Room 307 - Session AS+VT-FrM

Application of Surface Analysis Techniques to Semiconductor Technology

Moderator: F.A. Stevie, Cirent Semiconductor

8:20am **AS+VT-FrM1 An Overview of the Applications of Surface Analysis Techniques in Semiconductor Technology**, ***B.R. Rogers***, *R. Gregory, G. Harris, D. Werho, W. Chen,* Motorola, Inc. **INVITED**

Over the years the role of surfaces and interfaces has become increasingly important in determining the performance of semiconductor based microelectronic circuits. Consequently, the use of both new and traditional surface analysis techniques in the development of materials and processes as well as in manufacturing metrology and trouble shooting has become more and more popular. This presentation will review the strengths and weaknesses of the more common surface analysis techniques, such as Auger electron spectroscopy, Rutherford backscattering spectrometry, secondary ion mass spectrometry, total reflection x-ray fluorescence, and atomic force microscopy. Some of the newer scanning probe based techniques, such as scanning thermal microscopy and scanning capacitance microscopy, will be introduced. Several application examples will be presented to highlight the strengths and complimentary nature of these techniques. These examples will include: analysis of barrier metal composition as a function of depth into device features, two dimensional dopant profiling, measurement of ion implantation damage in SiC, analysis of fluorinated silicon dioxide film stability, development of wafer cleaning techniques, and the optimization of chemical mechanical polishing processes.

9:00am **AS+VT-FrM3 An Evaluation of SIMS Analytical Capabilities For Sub-0.25 Micron Implant Technology**, ***V.K.F. Chia***, Charles Evans & Associates

The applications of SIMS (secondary ion mass spectrometry) to the microelectronics industry are very diverse. In the ion implantation sector SIMS is perhaps the most widely used analytical technique. This is not too surprising because SIMS can detect all elements, produce high precision profiles, and provide elemental surface and bulk information with excellent detection sensitivity. As the design rule continues to shrink the question that arises is, "Can SIMS still be a valuable tool?". This paper addresses this question and reviews advances made in protocol development. For example, SIMS can perform high precision implant characterization (HPIC) to match the dose delivered by two different implanters to within <1% (67% confidence interval) during process replication or transfer, and for initial implanter qualification during fab start-ups. A better understanding of near-surface profiling phenomena has led to more accurate depth profiling of ultra-low energy ion implants (e.g. <1 keV B). SurfaceSIMS was developed to monitor and accurately quantify unintentional contamination that occurs during ion implantation, for example dopant cross-contamination in multi-purpose implanters, and to monitor inadvertent contamination related to sputter erosion or outgassing of implanter construction materials. As device dimensions shrink in size the need to perform ion implant characterization in small areas with high sensitivity becomes increasingly important. One solution is to interleave reactive primary ion species with high current density probes. This procedure enables 12 µm x 12 µm areas to be depth profiled with a sensitivity similar to analyzing a 180 µm x 180 µm area using Cs primary ions alone. In view of these advancements, SIMS appears to be well positioned to continue its primary role in ion implant characterization beyond the year 2000.

9:20am **AS+VT-FrM4 Accurate Dynamic Secondary Ion Mass Spectrometry (SIMS) and Auger Electron Spectroscopy (AES) Characterization of SiGe Stoichiometry and Hetero-Junction Bipolar Transistor (HBT) Dopant Levels**, ***T.H. Büyüklimanli***, *J.T. Mayer, M.S. Denker, R.L. Moore, C.W. Magee,* Evans East

The recent growth of the consumer microwave electronics market has spurred the development of SiGe HBTs. There are several physical and chemical properties of the device that affect performance and most importantly bandwidth. This has prompted us to take a fresh look at the acquisition and quantification of the SIMS and AES data. This paper investigates the characterization of two parameters of device fabrication: first the stoichiometry of the Ge-doped base layer, second the dopant (typically B) and impurity (typically O) concentration and distribution in the base layer. SIMS and AES were used to characterize a sample set ranging from 5-45 atomic percent Ge. Each sample was ion implanted with B, P, C and O. Differences in sputter rates, recommended analytical protocols (SIMS), data post-processing and changes in relative sensitivity factors will be addressed.

9:40am **AS+VT-FrM5 A Comparison Auger and TOF-SIMS Depth Profiling of Silicon Oxide Nitride Multilayers Using Low Incident Ion Energy**, ***S.E. Molis***, *R.E. Davis,* IBM Corporation, East Fishkill Facility*; D.W. Kisker,* IBM Research Division*; D. Paul,* Physical Electronics

The ever-shrinking dimensions of semiconductor devices have placed steadily more difficult challenges in front of analytical instruments and methods as well as fabrication tools and processing. In the future, this shrinkage will have a proportionally greater impact on the vertical dimensions. The SIA Technology Roadmap lists for example a gate oxide thickness equivalent of 2-3 nm by the year 2001, and a phasing out of SiO2 in favor of alternative dielectric materials. The difficulty of this analytical challenge makes it likely that no single technique will be able to tackle any type of complex process problem alone. Rather, a synergistic approach involving the strengths of each will be called for. New techniques are needed, and the current limits of current techniques must be extended. This paper describes one approach, teaming TOF-SIMS and Auger electron spectroscopy, with sputter ion gun designs which can provide adequate sputter rates at impact energies of less than 500 eV, to improve depth resolution. A Ni-Cr multilayer standard of thicker dimensions was used to measure and optimize experimental conditions. A set of various thin oxide and nitride single films and multilayers wa examined by both techniques, to mutual advantage. The TOF-SIMS approach generally gave superior depth resolution compared to Auger, although not as good as the structural view of X-TEM. The SIMS matrix effect was interpreted by comparison to the Auger profiles. TOF-SIMS was able to give some insight into the question of hydrogen content of the films. The propensity for thermal damage was also studied.

10:00am **AS+VT-FrM6 A New High Performance TOF-SIMS Instrument for 300 mm Wafer Inspection**, ***E. Niehuis***, *C. Bendel, D. Rading,* ION-TOF GmbH, Germany

We have developed a high performance TOF-SIMS instrument for the analysis of wafers up to 300 mm diameter. It includes a new sample stage with 5 axis and interferometric x,y position control for ultimate navigation accuracy. The instrument is equipped with a Ga liquid metal ion gun for surface analysis and imaging, and a flexible dual source gun with electron impact and Cs source for dual beam depth profiling. In a production environment high sample throughput, high reproducibility and ease of use are most important. To meet these requirements, we implemented complete instrument automation to setup the instrument for a specific task, to find a specific area on a wafer and to acquire and analyze the data. The navigation part includes the import of coordinates from other inspection tools, an auto-heigth-adjustment and optical pattern recognition. For the interpretation of the spectra we make use of a high mass resolution SIMS database for automated compound identification. In this paper we will describe the instrument performance and discuss the various applications of this tool in IC production. TOF-SIMS can be used for the screening of various surface contaminants like trace metals (alkali, transition metals), small inorganic molecules (e.g. sulfates) as well as organic contaminants (e.g. photoresist residues, cleaning agents, plasticizers from storage containers). The technique also offers depth profiling with excellent depth resolution for the characterization of gate oxides and ultra-shallow implants. In defect review TOF-SIMS provides high lateral resolution and detailed chemical information on sub-micron particles.

10:20am **AS+VT-FrM7 Automated Process Monitoring Using ESCA and Numerical Methods**, ***D.J. Hook***, *J.F. Moulder, J.S. Hammond,* Physical Electronics, Inc.

There currently exists a need in the electronics industry for automated process control to increase product yield and reliability. An example of this is the hard disk industries' push to higher media storage density that has placed increasingly stringent requirements on the lubrication media needed for disk surfaces. Similarly, uniformity of oxide thickness on silicon wafers is an important property that can affect the finished device and in turn overall production capability of a semi-conductor facility. The ability to obtain quantitative ESCA results over large areas and present information in an easy to understand visual format can provide feedback for the production environment. The combination of totally automated process monitoring with Graphical User Interface (GUI) driven film thickness calculations and large area mapping software is a new development in ESCA which can address this need. Examples of automatically collected

lube thickness measurements on new and used hard disks and oxide thickness maps on cleaned 200 mm silicon wafers will be presented.

10:40am **AS+VT-FrM8 Measurement of Carrier Concentration and Lattice Absorption in Bulk and Epitaxial Silicon Carbide Using Infrared Ellipsometry**, ***T.E. Tiwald,*** University of Nebraska, Lincoln*; S. Zollner,* Motorola Semiconductor Products Sector*; J.A. Woollam,* University of Nebraska, Lincoln*; J. Christiansen,* Motorola Semiconductor Products Sector*; P.G. Snyder,* University of Nebraska, Lincoln

We have measured the dielectric function of bulk nitrogen-doped 4H and 6H SiC substrates from 700 to 4000 cm@super -1@ using Fourier-transform infrared spectroscopic ellipsometry. We observe a strong reststrahlen band between 800 and 1000 cm@super -1@ due to photon absorption by transverse optical phonons. The shape of this band is influenced by plasma oscillations of free electrons, which can be described with the Drude model. A detailed analysis of the data allows the determination of the free electron concentration, which is between 10@super 18@ and 10@super 19@ cm@super -3@, in good agreement with electrical measurements. We were also able to determine the surface layer thickness for epitaxial 4H SiC (with an electron concentration of 10@super 16@ cm@super -3@) on heavily-doped bulk 4H SiC. Finally, we observe Berreman peaks near the longitudinal optical phonon energy in all samples. These interference effects are the result of carrier depletion and accumulation near the surface. The effect is strongest in the epitaxial sample and the more lightly doped substrates.

11:00am **AS+VT-FrM9 Si Dopant Site Within Ion Implanted GaN Lattice**, ***H. Kobayashi,*** *W.M. Gibson,* State University of New York, Albany

There has been considerable interest in GaN for the fabrication of blue light emitting devices. In addition, this material is attractive for use in high temperature or high power electronic devices. Therefore, ion implantation for selective area doping is becoming more important for future Ga N device technology. It has been demonstrated that Si and Mg ion implantation and post-implant annealing are useful to obtain n-type and p-type GaN, respectively. However, there is still little information on actual lattice lo cation of impurities. We have investigated the Si dopant site in the GaN la ttice using ion channeling technique in combination with Rutherford backscattering spectrometry (RBS), particle induced X-ray emission (PIXE) and nuclear reaction analysis (NRA). Metalorganic chemical vapor deposition (MOCVD) grown GaN on a c-plane sapphire substrate implanted with @super 28@Si at a do se of 7x10@super 14@cm@super -2@ with post-implant annealing was investigated. Channeling measurements were performed by taking angular scans around the and axes and recording RBS, PIXE and NRA yields for Ga, Si and N, respectively. The channeling results indicate that almost 100 % of Si goes into the Ga site when the samples are annealed at 1100°C for 30 minutes while for annealing at 1050°C and below, Si is distributed almost randomly. This suggests that a drastic change of Si substitutionality takes place in a narrow temperature region near 1100°C. Our results directly indicate that the electrical activation of Si implanted GaN with post-implant annealing is due to the formation of substitutional Si at this temperature.

11:20am **AS+VT-FrM10 Laser Assisted Etching of InP Studied with XPS**, ***D.M. Wieliczka,*** *J.M. Wrobel, C.E. Moffitt,* University of Missouri, Kansas City*; J.J. Dubowski,* National Research Council of Canada, Canada

X-ray Photoelectron Spectroscopy (XPS) and Scanning Electron Microscopy (SEM) have been used to study the surface chemistry and morphology of InP wafers after photo-chemical etching of the surface. The etching process employed 308 nm illumination from a XeCl excimer laser in conjunction with a low pressure atmosphere of 10%/90% Cl@sub 2@/ He mixture. The samples were exposed to laser radiation with fluences ranging from 73 mJ/cm@super 2@ to 210 mJ/cm@super 2@. The lower fluence is well below the ablation threshold for InP under vacuum conditions. The use of a Kratos AXIS-HS photoelectron spectrometer allowed for mapping the surface chemical composition within the illuminated region and in the vicinity with a 60 μm spot size. Photoelecron spectral lines from In, P, Cl, C, and O were monitored for determining the surface chemical composition and for creating surface maps of the illuminated regions. The results showed a distinct correlation between surface chemical composition and laser fluence. At high fluence levels, the surface composition changed dramatically between the illuminated region and the exterior. Evidence for In-Cl compounds was found within the crater with thermal processes occurring in the region near the crater. At low laser fluence, the etching process showed no thermal effects in the near crater region and produced a crater with minimal Cl incorporation. In addition to the chemical changes with fluence, the surface morphology is dramatically altered. At high fluence levels, SEM images indicate the etched surface was rough and deposits of ablated material were left in the vicinity of the crater. At low fluence the images indicate a better surface morphology. This work was supported by the University of Missouri Research Board.

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