Flat Panel Displays Topical Conference
Room 604 - Session FP+VT-MoM

Field Emission Displays and Vacuum Packaging Issues

Moderator: W. Weed, Sandia National Laboratories

8:20am **FP+VT-MoM1 A New Field Emission Device with Improved Vacuum Features**, ***V.P. Mammana***, Instituto de Física - Universidade de São Paulo, Brazil; *F.T. Degasperi,* Faculdade de Tecnologia de São Paulo - FATEC/SP, Brazil; *O.R. Monteiro,* Lawrence Berkeley Laboratory; *J.H. Vuolo, M.C. Salvadori,* Instituto de Física - Universidade de São Paulo, Brazil; *I.G. Brown,* Lawrence Berkeley Laboratory

We introduce in this article a novel geometry that can be used in the manufacturing of field emission displays that combines superior vacuum conductance and field enhancement factors. A theoretical model is developed for the calculation of the upper limit of the electrostatic field at the emitting regions, and these values are compared to those calculated for the actual geometry. The vacuum conductance of the proposed geometry is also calculated, and we show that conductances up to an order of magnitude higher than other schemes are readily achievable.

8:40am **FP+VT-MoM2 Fabrication of a Well-Type Field Emission Device with a Tungsten Doped Zinc Oxide Thin Film Phosphor**, ***V. Bhatia***, *J.B. Sobti, L.D. Karpov, M.H. Weichold,* Texas A&M University

Interest in the area of the field emission displays (FEDs) exists because of combination of the positive features of a cathode ray tube with flat panel display technologies. High resolution at low cost, power efficiency at low voltage operations, wide viewing angles, and operation under variable temperatures are some of the important features of an FED. This paper reports the fabrication of a monochromatic display of blue light from a lateral edge well emitter. A high-resolution display has been fabricated using a blue phosphor developed at TAMU@footnote 1@ in conjunction with a well type edge field emission device designed by Karpov et al.@footnote 2@ The FED has been formed by constructing arrays of wells, having sides of a dielectric material above a matrix of anode lines. The anode lines lie underneath the phosphor. In the diode design of the device, cathode lines are fabricated by depositing metal-carbon-metal layers, atop the well sides, hanging slightly over the well edges. The FED design reported here provides an extra measure of brightness to the display by reflecting the light from anode lines out of well towards the viewer. Since the device eliminates the fabrication of microtips, the display involves simpler fabrication steps, more ruggedness, and stability than conventional FEDs. The phosphor being used in this display, has been fabricated by co-depositing zinc oxide and tungsten (ZnO:W). This phosphor has been reported to emit blue light at 490 nm when excited at 300 V.@footnote 3@ This paper presents ongoing research in integrating the ZnO:W phosphor in the well type edge field emission display. The fabrication steps involved in making the display device are presented as are emission properties and current-voltage characteristics to determine the performance of the display. @FootnoteText@ @footnote 1@Technology Disclosure to TAMU Technical Licensing Office (1993). @footnote 2@L. D. Kapov et al. 7th Int'l Vacuum Microelectronics Conf., France 1994. @footnote 3@J. B. Sobti et al. MRS meeting, Spring 1998.

9:00am **FP+VT-MoM3 Effects of Residual Gas Exposures on the Emission Characteristics of Field Emission Arrays**, ***R.M. Wallace***, *B.E. Gnade,* University of North Texas; *B.R. Chalamala,* Motorola Flat Panel Display Division **INVITED**

Field emitter arrays have been introduced as a potential component for flat panel display technologies. A key issue for reliable performance includes the consideration of the device vacuum ambient in the course of packaging the display. In this paper, we review the effects of residual gas species on the emission characteristics of field emitter arrays under carefully controlled UHV conditions. We also examine recent work in the community on controlling the tip morphology, the tip surface chemistry, and the sources of residual gas species in displays.

9:40am **FP+VT-MoM5 Pressure Field Detailed Calculations for a New Field Emission Device with Improved Vacuum Features@footnote 1@**, ***F.T. Degasperi***, Faculdade de Tecnologia de São Paulo - FATEC/SP - Brazil; *V.P. Mammana,* Instituto de Física da Universidade de São Paulo, Brazil

The vacuum characteristics are an important consideration for field emission devices, mainly because of the high area/volume ratio presented in these devices. Dessorption associated with relatively small conductances can degrade the device performance over its lifetime, if small distances between the cathode and the anode are set. The proposal of a novel geometry for these devices@footnote 1@ seeks superior vacuum conductance, while maintaining a high electric field enhancement factor. It is of great importance to determine the pressure distribution along the emission chamber of the proposed device, since the emission performance is strongly dependent on this pressure. The usual vacuum technology approach considers a vacuum system made up of discrete elements. This approach is very useful, but leads only to the knowledge of the average pressure, and not to the detailed pressure distribution. In this article we calculate the pressure distribution considering the degaseification effect from several surfaces of the device, which allows us to predict its vacuum behaviour in a more realistic situation. @FootnoteText@ @footnote 1@ see "A new field emission device with improved vacuum features".

10:00am **FP+VT-MoM6 Cathodoluminescent (CL) Degradation Mechanism for ZnS-Based Phosphors and the Impact on Field Emission Displays (FEDs)**, ***B.L. Abrams***, *W. Roos,* University of Florida; *H.C. Swart,* University of the Orange Free State; *P.H. Holloway,* University of Florida

The surfaces of ZnS powder and thin film phosphors have been subjected to electron beam bombardment.Simultaneous acquisition of CL brightness data and Auger Electron Spectroscopy(AES)data have revealed a correlation between surface chemical reactions and CL degradation.The data were collected in a stainless steel UHV chamber.In the presence of a 2kV primary electron beam in 1e-6 Torr of H2O,the amounts of C and S on the surface decreased while the O concentration increased.XPS data showed that ZnO formed on both the samples.This change in surface chemistry coincided with a decrease in CL brightness.Our model of electron beam stimulated surface chemical reactions(ESSCR)for this degradation process postulates that the primary electrons dissociate physisorbed molecules to reactive atomic species. These atomic species remove surface S and C as volatile SOx and H2S species allowing formation of a non-luminescent ZnO layer in 1e-6 Torr water.However,in a vacuum of 1e-6 Torr dominated by hydrogen and with a low water content, there was no decline in S,no rise in O,but the CL still degraded.These effects are still attributed to ESSCR due to hydrogen assisted by thermal effects.Hydrogen is postulated to dissociate under the electron beam and remove S as H2S while Zn volatilizes due to a high vapor pressure and elevated temperatures from electron beam heating.The desorption of various ions or molecules from the surface of the phosphor caused by surface chemical reactions contaminate the vacuum inside the display tube and create a reactive environment.These reactive atoms or molecules may adsorb,react and consequently form an absorbed or coated layer(sulfide or oxide)on the field emitter tip on the cathode side of the FED.It is thus suggested that the ESSCR mechanism is important to degradation both of the phosphor on the anode and the field emitter tips on the cathode.This work was supported by Darpa Grant MDA 972-93-1-003 through the Phosphor Technology Center of Excellence.

10:20am **FP+VT-MoM7 A Novel Electron Emission Flat Panel Display Using Cesiated Amorphous Diamond Planar Emitter Structure**, ***S. Kim***, *M.H. Sohn, Y.S. Park, N.W. Paik, B. Lee,* SKION Corporation; *Y.H. Lee,* Sung-Kyun-Kwan University, S.Korea, Korea; *D.H. Lee, Y.J. Sung,* Sung-Kyun-Kwan University, S.Korea; *G.Y. Yeom,* Sung-Kyun-Kwan University, S.Korea, Korea

Oxidized cesiated amorphous diamond films have been developed for electron emitters. The work function of the surface is as low as 1.05 eV. The work function, chemical composition and structure are found to be stable even after annealing at temperatures up to 700 degree C. A very low turn-on field of 5-7 V/µmm is obtained by a planar geometry field emission measurement. A unique Pierce-type planar electron extraction geometry has been developed for flat panel display applications. Unlike field emission from a sharp point, the structure produces a long focal length beam of the order of few centimeters. In this paper, the fabrication procedure of the emitter structure and its emission properties will be presented.

10:40am **FP+VT-MoM8 Field Emission Properties of Conformal and Non-Conformal Diamond Film Coatings on Si Microtip Electron Emitters**, *M.Q. Ding,* Beijing Vacuum Electronics Research Institute, China; ***A.R. Krauss***, *O. Auciello, D.M. Gruen, Y. Huang,* Argonne National Laboratory; *V.V. Zhirnov,* Semiconductor Research Corp.; *E.I. Givargizov, A. Stepanov,* Institute of Crystallography, Russia

Non-conformal and conformal nanocrystalline diamond films were deposited on single needle-shaped Si tip emitters, using hot filament chemical vapor deposition (HFCVD) and microwave plasma-enhanced chemical vapor deposition (MPECVD), respectively. The HFCVD diamond was deposited in the form of large single crystal grains at the end of the

microtips, whereas the nanocrystalline diamond films were uniformly thick conformal coatings. The threshold voltages for cold cathode electron emission were measured for Si microtips as a function of both the thickness of the diamond coating and the radius of the Si tips. The threshold voltages for the single crystal HFCVD coatings were found to vary with both the tip radius and diamond film thickness. For the nanocrystalline films, the threshold fields were found to be significantly lower than the uncoated tips, and nearly independent of both Si tip radius and film thickness. In this case, the behavior is consistent with field emission that is determined largely by local electric field enhancement associated with intrinsic film properties. A model is presented in which the field enhancement occurs at sp2-bonded grain boundaries. Work supported by the U.S. Department of Energy, BES-Materials Sciences, under Contract W-31-109-ENG-38, and ER-LTR CRADA No. C9501501 with SI Diamond Technology, Inc., Austin, TX, and DARPA/ONR under Contract N00014-97-F0305 The submitted manuscript has been created by the University of Chicago as operator of Argonne National Laboratory under contract no. W-31-109-ENG-38 with the U. S. Department of Energy. The U. S. Government retains for itself, and others acting on its behalf, a paid-up, non-exclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the government.

11:00am **FP+VT-MoM9 Fabrication of Aligned High-density Diamond Needles by Dry Etching of Diamond Substrates**, *E.S. Baik,* Myong Ji University, Korea*; Y.J. Baik,* Korea Institute of Science and Technology, Korea*; **D. Jeon**,* Myong Ji University, Korea

Densely packed diamond needles aligned in the same direction are formed by air plasma etching of diamond substrates. Diamond substrates were coated with a thin layer of Mo and then etched by RF or DC plasma with the substrate biased at negative several hundred volts. The shape and the density of the diamond needles could be reproducibly controlled with the etching parameters such as the substrate temperature, pressure, bias voltage, power, and the amount of Mo. If the substrate temperature was high, for example, the needles became thick. Mo acted as an etch-resistant mask for the needle formation. Mo was sometimes self-supplied by the sputtering of the Mo substrate holder during the etching, but the uniformity of the needles could be best controlled by coating small amount of Mo before etching. If the amount of Mo or the pressure was not adequate, the needles did not form or formed only along the edge of the diamond grains. With the optimum condition, we could fabricate sharp diamond needles whose pillar diameter and height were 0.1 μm and 3 μm, respectively. The density was 30 needles/μm@super 2@. Since the needles were highly aligned and always formed in parallel with the field, the direction of the needles could be chosen by tilting the substrate. Not only the polycrystalline diamond films but also the high pressure/high temperature diamond and the natural diamond could be etched to form needles. Our diamond needles can be utilized as the field emission cathode tips, diamond fiber for composite materials, highly efficient heat sinks for their large surface area, and sensors.

11:20am **FP+VT-MoM10 Hermetic Sealing and Evacuation of Candescent's ThinCRT@superTM@**, ***T.S. Fahlen,*** Candescent Technologies Corporation

INVITED

Candescent has developed a full color, full video, power efficient display, the ThinCRT@superTM@ based on Spindt-type field emitters with very low voltage switching (<10.5 volt), and "high voltage" (6 KV) aluminized phosphors. Because of the high voltage used, the faceplate (anode/phosphor screen) and backplate (cathode) of the display are separated by 1.25 mm. This talk describes two methods used to hermetically seal the perimeter and evacuate ThinCRT displays. In both methods, the faceplate and backplate are sealed to a frame made of glass frit placed between them following an accurate, room temperature and atmospheric pressure alignment procedure. One sealing method uses a laser to first seal the frit frame to the faceplate, and then to hermetically seal the backplate to this assembly in a vacuum environment; no exhaust tubulation is required, and a non-evaporable getter is incorporated along one internal border of the display. A second method uses a laser to seal the frit frame to the faceplate, and the backplate to the frame/faceplate assembly but in a non-vacuum environment. An auxiliary chamber (AC) containing a getter and exhaust tube is then oven sealed to the rear of the assembly. Holes in the backplate allow the gases in the interior of the display to flow into the AC. The display assembly is then evacuated through an exhaust tubulation. The AC saves border space by allowing the getter to be removed from the display border to the rear of the display. The AC adds no additional thickness to the display because it protrudes no further than do the display electronics which are also attached to the rear of the display. In both sealing methods, the exact spacing between the faceplate and the backplate is determined solely by the internal support structure. The frit frame and sealing process have been designed so that during laser sealing, the frit expands to fill and seal the small gap left between the frit frame and the faceplate.

Vacuum Technology Division
Room 610 - Session VT-TuM

Total and Partial Pressure Gauging

Moderator: Neil Peacock, MKS Instruments, Inc.

8:20am **VT-TuM1 Recommended Practice for Calibrating Vacuum Gauges of the Thermal Conductivity Type**, ***A.P. Miiller***, National Institute for Standards and Technology; *R.E. Ellefson,* Leybold Inficon Inc.

Thermal conductivity gauges (TCGs) are used extensively in the pressure range of the order of 10@super -1@ Pa (10@super -3@ Torr) to atmosphere. This presentation summarizes the content of a recently completed Recommended Practice for calibration of thermal conductivity gauges. The recommended calibration hardware references capacitance diaphragm gauges as the transfer standard for a practical calibration gauge. The vacuum system and gas handling methods are also presented. The calibration methods recommended are similar to those used by manufacturers for factory calibrations of their TCGs. The expected accuracy of a TCG is in the range of 5 % to 20 % of reading. This recommended practice provides users with a method for their calibration as well as good practices for the use of these gauges in vacuum applications.

8:40am **VT-TuM2 The Use and Calibration of Spinning Rotor Gages at Non-Ambient Temperatures**, ***C.R. Tilford***, National Institute of Standards and Technology, US; *B. Lindeanau,* FZJ-IGV, Germany

Many applications require accurate low pressure measurements at temperatures different from room temperature. These measurements are complicated by thermal transpiration effects and the thermal and chemical perturbations associated with most high vacuum gages. The use of an in situ spinning rotor gage (SRG) is a possible solution for such problems. The SRG is stable, inert, and its power disappation is in the milliwatt range. However, for the most accurate measurements it must be determined if the effective accomodation coefficient, the factor determining the sensitivity of the SRG, is temperature dependent. This talk describes the design and performance of a calibration system that corrects for thermal transpiration effects and allows the in situ calibration of SRGs for temperatures between 77 K and 400 K. This system has been used to investigate the temperature dependence of the effective accomodation coefficients for both "smooth" and deliberately roughened steel balls used as SRG rotors.

9:00am **VT-TuM3 Extension of the Spinning Rotor Gauge to Lower Pressure**, ***J.P. Looney***, National Institute of Standards and Technology

The Spinning Rotor Gauge (SRG) is widely used for vacuum gauge calibration and measurement in the pressure range 0.1 Pa to somehwat below 10 @super -4@ Pa (10 @super -6@ Torr). The lower limit of presently available SRGs is due to essentially two factors (i) the ability to measure the rotor deceleration rate with a precision of better than about 10 @super -10@ s @super -1@ and (ii) large residual torques on the rotor. The first can be overcome by improved timing of the rotation rate of the ball and the second can be overcome by development of suspension heads with smaller residual torques on the spinning rotor. Together, a system can be constructed to make measurements to much lower pressures, perhaps below 10 @super -6@ Pa (10 @super -8@ Torr) with an imprecision of <1% for a four minute measurement interval. The factors which limit the useful pressure measurement range of the SRG will be dicsussed and initial performance measurements for a prototype system will be presented.

9:20am **VT-TuM4 Enhanced Bayard-Alpert Gauge with Accuracy and Stability Improved by Design and Construction**, ***P.C. Arnold***, Granville-Phillips, Division of Helix Technology Corp. **INVITED**

An enhanced accuracy and stability Bayard-Alpert gauge, now in general use for over five years, is reviewed. The philosophy of its design to control electron trajectories, location of ion generation, efficiency of ion collection, and maintenance of these characteristics is described with respect to computer simulation and its resultant gauge construction. Gauge sensitivity variation with pressure, from gauge to gauge, and over five years of operation is presented. A system for multi-gauge calibration is described as well as the system for maintaining the reference standards. Analyzing commercial use of this gauge in process environments over these five years has revealed knowledge relating to degradation of the function of each gauge electrode. Also analyzed are the process cycle requirements of quickly measuring base pressure under process conditions versus backfilling to pressures well above base pressure. Many of these concepts are generally applicable to most ionization gauges and will be discussed.

10:00am **VT-TuM6 A Miniature Dual-Collector Ionization Gauge**, ***A.R. Filippelli***, Granville-Phillips, Division of Helix Technology Corp.

In recent years there has been a trend to reduce the physical size of the sensors used in the semiconductor manufacturing industry. Because of the great utility of the Bayard-Alpert ionization gauge in this industry, it is natural for gauge manufacturers to ask: Can we retain its basic three-element design, operating voltages, good sensitivity, and low x-ray limit and, at the same time, significantly reduce its size? The answer is yes. This talk will introduce the basic concept that motivated a dual-collector design and will then trace the development of the miniature gauge based on this concept. Some details of the design were guided by use of a modeling program, and examples of ion and electron trajectories computed using this program will be shown. Experimental testing of prototypes, in conjunction with modeling, was used to select other design parameters such as filament length, collector diameter, and grid end geometry. Experimentally-determined test results for sensitivity and x-ray limit will also be presented. While no single design factor appears to dominate the gauge's performance, the combination of design choices has resulted in a gauge with good sensitivity as well as a significantly smaller size.

10:20am **VT-TuM7 A Compact Wide-Range Cold-Cathode Gauge**, ***B.R.F. Kendall***, Elvac Laboratories; *E. Drubetsky,* The Fredericks Company

Cold-cathode ionization gauges offer many advantages for routine high-vacuum measurements. They are simple and robust. Thermal outgassing and electron-stimulated desorption, both significant problems in hot-cathode gauges, are negligible. There are no x-ray effects to cause errors at low pressures. New design techniques have largely eliminated stray-field and starting problems. The design, development and testing of a compact wide-range cold-cathode gauge are discussed. Demountable and all-metal versions have small internal volumes ranging from 5 to 15 cm@super 3@, yet the sensitivity can exceed 10A Torr@super -1@ at 10@super -6@ Torr. Double inverted magnetron geometry and shielding rings reduce the external magnetic fields to very low levels. The anode contains thorium for easier starting at normal pressures. For UHV applications, Americium 241 or a carbon film cold emitter can be used for instant starting. Test data are given which illustrate the effects of varying anode voltages and magnetic fields upon sensitivity and starting time. Factors affecting stability and freedom from discharge discontinuities are also discussed. Design features allowing stable operation down to 10@super -11@ Torr and above 10@super -2@ Torr are described.

10:40am **VT-TuM8 New Enhanced Performance Low Pressure Capacitance Manometer**, ***C.P. Grudzien***, MKS Instruments

The measurement performance of low pressure capacitance manometers has traditionally been influenced to varying degrees by many factors including barometric pressure, ambient temperature change, shock, vibration, material creep and rapid pressure excursions. Many improvements and developments have occurred since the original capacitance manometer technology was invented over forty years ago. Previous capacitance manometer designs address several of these pressure independent influences, but in the process, trade off performance in other areas. A new enhanced performance design is described here that incorporates several unique approaches to reducing these influences and provides for a practical, robust platform. The unique radial 'spoke' geometry isolates the sensitive capacitance elements from unwanted body forces and thermal transients, yielding stable zero and span performance. Experimental data and computer simulation show that measurements using instruments with full scale ranges of 100 mTorr (~10 Pa) and below are superior to that of previous state-of-the-art methods. The enhanced performance capacitance manometer design establishes a basis for continual improvement and a path to meet the future requirements of the vacuum community.

11:00am **VT-TuM9 A Review of Thermal Transpiration Corrections in Capacitance Diaphragm Gauges**, ***J. Setina***, Institute of Metals and Technology, Slovenia

Capacitance diaphragm gauges (CDGs) play important role in vacuum metrology because of their accuracy and resolution. They are widely used in calibration laboratories as reference and transfer standards for calibration of other pressure measuring devices in the pressure range from 0.01 Pa to 100 kPa. CDGs are inherently susceptible to ambient temperature variations. Operating CDGs at stabilised elevated temperature greatly improves the zero stability and enables relative resolution of few

ppm of gauge full-scale but also introduces nonlinearities, which are known as thermal transpiration (TT) effect. In applications, where the uncertainty of measurements must be reduced to less than one percent, the response of CDG has to be corrected for TT effect if measured pressure is below 100 Pa. TT effect had been studied in detail by Takaishi and Sensui,@footnote 1@ and their empirical formulas are widely accepted for corrections of CDG measurements. In the present paper we will address the accuracy of this formulas which were published four decades ago. We have done some accurate calibrations of CDGs in the pressure range from 0.01 to 133 Pa in four gases: N@sub 2@, Ar, He and H@sub 2@. For He we found discrepancy of our data from Takaishi and Sensui empirical formula as large as 0.3 % in the range of pressures from 0.5 to 5 Pa. Scaling of thermal transpiration curves for different gases with the inverse of Knudsen number was also observed. This has not been reported by other authors. Vacuum metrology greatly advanced since the work of Takaishi and Sensui. The improvement in measurement accuracy at primary laboratories in the past ten years allows much more precise measurements in the range from 0.01 to 100 Pa. Therefore we suggest a thorough re-evaluation of the TT effect that should include a variety of gases with which CDGs are commonly used as well as the influence of momentum exchange of gas molecules on the surface of the tube that connects a CDG to the vacuum system. @FootnoteText@ @footnote 1@ Takaishi T., Sensui Y.,Trans.Faraday Soc., 1963, 59, p. 2503

11:20am **VT-TuM10 Partial Pressure Analyzers in the Relativistic Heavy Ion Collider***, **L.A. Smart**, D. Loughlin, R.J. Todd, R.C. Lee,* Brookhaven National Laboratory

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory incorporates large-scale high and ultrahigh vacuum systems. Partial pressure analyzers (PPAs) are employed to monitor the gas composition of these volumes remotely. PPAs with faraday cup detectors are placed along cryostat vessels that are up to 480 meters long. Data trends in both displacement and time are used to indicate helium or air leaks into the system and their probable locations. Electron multiplier units are employed to peer into the ultrahigh vacuum beam chambers near the interaction region detectors, where beam-on-beam collisions occur. The acquisition, testing, installation and control of the PPAs will be discussed with a summary of the system performance in the first few months of RHIC operation.

11:40am **VT-TuM11 The Modern and Flexible Upstream Controller***, **H.-Ch. Gehlhar**,* Leybold Inficon, Liechtenstein

The modern vacuum applications ask more and more for constant pressures in chambers and reactors or constant gas flow to maintain certain atmospheres in those chambers. This can be done in different ways, e.g. downstream control, massflow control or as we would like to discuss now by upstream control. A very simple version of upstream control could be a limit switch controlled valve operation by just opening or closing the valve. A simple and inexpensive method with all pros and cons concerning any system requirement. As an improvement to this, modern upstream controllers are flexible and give various opportunities to justify the pressure control circle in a vacuum system. The parameters to take care of like: chamber size, pumping speed, response times, time requirements etc. are very well known by everyone who has ever designed such a control circle. The user requirements of the vacuum system combined with all these parameters result in a level of requirements of a controller and a valve as well as for the applied gauges. Those requirements may vary in such a wide range that many pressure controllers are by far out of their limits. Modern solutions for pressure controllers or upstream controllers may not cover every extreme requirement. These new and advantageous controllers give flexibility in choosing out of various gauges and allow to justify the PID parameters in a wide range that nearly most of the known applications are covered in a satisfying way.

Vacuum Technology Division
Room 610 - Session VT-TuA

Vacuum Contributions to the Semiconductor Industry (1950-1975)

Moderator: R.E. Ellefson, Leybold Inficon, Inc.

2:00pm **VT-TuA1 Vacuum Systems, Deposition Sources, Measurement and Control Tools for the Semiconductor Industry (1950-1975)*, D.E. Meyer,*** Consultant **INVITED**

The purpose of this presentation is to relate and discuss how VS&T (vacuum science and technology) impacted the semiconductor industry prior to 1976. The major portion of the talk will feature research, development, production, and quality and reliability experience at Texas Instruments. But company interactions with the rest of the SC industry and the military and space agencies also provide noteworthy examples of VS&T's contributions. Initially, military requirements for performance and reliability were the driving force. Device stability and manufacturability (read yield) were key to industry growth as well. All of these it turns out were highly dependent upon equipment, processes, and control of various thin film depositions in device manufacture and vacuum techniques in package assembly. A progression of improved technology and equipment will be described including the change from filament to eb-gun deposition, from oil pumped to high vacuum dry pumped systems, process control and reliability assurance using RGA, scanning electron microscopy, and current-temperature stressing. Both early bipolar and MOS processing will be addressed. The data presented and discussed will show how significant VS&T was to the growth of the SC industry and will consist of both a review of published and unpublished information.

2:40pm **VT-TuA3 Evolution of Integrated Circuit Vacuum Processes: 1962-1975*, R.K. Waits,*** Technical Marketing Programs **INVITED**

The quarter-century from 1950 to 1975 witnessed the introduction of an extraordinary sequence of revolutionary semiconductor products: the silicon transistor, the integrated circuit (IC), the semiconductor memory, and the microprocessor. This ever-increasing complexity was made possible by many small breakthroughs in manufacturing technology involving new fabrication processes and measurement methods. Often an innovation involving vacuum technology appeared at just the right time to make possible the next technological leap. The metallization process is a good example. The components in the first practical IC were interconnected with a patterned layer of vacuum-evaporated aluminum. When the MOS field-effect transistor was perfected, it required a sodium-free evaporation process and the magnetically-focused electron-beam evaporation source propitiously arrived to save the day. As metal connections got narrower, strange failures began to occur. The scanning electron microscope (operating under vacuum, of course) was a new tool that let us examine the surface of an IC as if we were standing on its surface and gazing around. The failures were seen to be caused by microcracks in the metal lines as they crossed over steps in the circuit topography. Geometrical analysis showed that gaps were caused by shadowing during vacuum deposition. Methods were devised increase the mobility of the depositing aluminum atoms so that they would fill in the gaps during film growth. Metallization failures due to electromigration, and the shorting of shallow junctions by silicon diffusion into the aluminum, had to be cured by adding small amounts of copper and silicon to the aluminum. New magnetron sputter sources came to the rescue. During these years, ion implantation, plasma etching, and low-pressure and plasma-enhanced chemical vapor deposition, all became manufacturing processes, and, without which, today's (and tomorrow's) ICs would not be possible

3:20pm **VT-TuA5 History of Plasma Ashing and Plasma Etching in the Semiconductor Industry from 1950 to 1975*, R.L. Bersin,*** Ulvac Technologies, Inc.

This paper will focus on the introduction of plasma etching and photoresist ashing from the late 1960's to 1975 as seen by International Plasma Corporation (IPC), the first company dedicated exclusively to the manufacture of "barrel" plasma ashers for the semiconductor industry [subsequently to be named Dionex Gas Plasma Systems, Branson IPC, and finally to disappear into Gasonics International]. The history from 1-inch wafers through 6-inch wafer development will be discussed in terms of equipment design features and process technology for both resist stripping and plasma etching. Limitations of isotropic etching and uniformity problems with barrel chambers are discussed; the introduction of the first multi-step automatic plasma ashing equipment is described. Early etching of oxide, nitride, and metals as well as stripping will be illustrated with SEM examples of the then current process technology and photographs of the equipment at that time.

3:40pm **VT-TuA6 History of Commercial Ion Implantation*, C.B. Yarling,*** EEESPEC/Ion Beam Press

In today's semiconductor manufacturing industry, doping of sub-micron junctions is impossible without the use of an ion implanter. Indeed, most process flows of advanced microprocessors and 256kb DRAMS being manufactured in modern class-10 wafer fabs contain more than 15 separate implant steps. And if one examines the National Technology Roadmap for Semiconductors (NTRS), it is clearly seen that the implanter continues to play a key role in an industry that has been richly filled with people and equipment. A historical perspective of ion implantation begins with its development in 1906, when Rutherford bombarded aluminum foil with an alpha particle, and ends in 1978, when it is generally considered that ion implanters came of age! Sandwiched between these two events are several key process and equipment developments: Schockley's patent on ion implantation (1954); delivery of the first industrial implanter (1960); the first doping implant in semiconductor manufacturing (1962); shipment of the first US commercial implanter (1967); and the first semiconductor wafer fab to use implantation on all devices (1970). This paper reviews the history of ion implantation, the genealogy of commercial implanter manufacturing companies, and visits some of the colorful people who have helped to make the industry what it is today. We see that a certain amount of incestuousness has enabled this industry to grow since its inception. Yet in today's business climate where acquisitions and mergers are the norm rather than the exception, we find only three remaining major US suppliers of ion implanters. Although new shallow doping technologies which may eventually replace some implant steps are being developed, it is clear that the ion implanter has enabled semiconductor technology to travel the NTRS roadmap, where microns of junction depths in the mid-1960's are now in the sub-micron regime at the start of the new millennium.

4:00pm **VT-TuA7 Application of Sub-atmospheric Plasmas to Semiconductor Device Processing*, D.M. Mattox,*** Management Plus Inc.

Sub-atmospheric pressure plasmas play a critical role in semiconductor device processing. Plasmas provide the ions used to sputter surfaces, modify film properties and affect the surface coverage by deposited films. Plasmas also 3activate2 reactive species to enhance chemical reactivity for reactive cleaning, deposition and etching processes. This paper reviews the history of using plasmas for surface preparation, PVD and PECVD film deposition, modification of film properties, reactive deposition and plasma etching to create film structures.

4:20pm **VT-TuA8 Refining Old Vacuum Knowledge for Today's Semiconductor Manufacturing Processes*, J.F. O'Hanlon,*** University of Arizona **INVITED**

In today's competitive manufacturing environment, it is necessary to use vacuum system processes which are reliable, repeatable and cost efficient. This knowledge which constitutes our understanding of vacuum science is vast, and has on occasion been forgotten or misused. This talk will review some important concepts which have been re-invented, or re-applied or misunderstood in the course of designing modern vacuum-based processing systems.

Vacuum Technology Division
Room 4C - Session VT-TuP

Poster Session

VT-TuP1 RGA Spectra of Vacuum System Contamination from Typical Cleaning and Handling Sources, ***R.S. Goeke***, *J.A. Romero,* Sandia National Laboratories

A library of typical RGA spectra has been generated for commonly used cleaning and handling materials that may lead to contamination in a baked vacuum system. Some of the materials analyzed were: Nitrile gloves, Brulin & Citrodet aqueous based cleaners, Fluoroware, Scotchbrite pads. Spectra were generated using a UHV desorption system with a Quadrupole Gas Analyzer. The purpose of the analysis was to generate a finger print library of possible contamination sources, which could be used to identify contamination in a production system. @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.

VT-TuP2 Application of Porcelain Enamel as a UHV Compatible Electrical Insulator, ***M.D. Mapes,*** Brookhaven National Laboratory, usa*; H.C. Hseuh, C. Biscardi,* Brookhaven National Laboratory

Many accelerator vacuum system components require electrical insulation internal to the vacuum system. Some accelerator components at Brookhaven National Laboratory are installed in UHV vacuum systems which require the insulation to have excellent vacuum characteristics, be radiation resitant and be able to withstand high temperatures when used on baked systems. Porcelain enamel satisfies all these requirements. This paper describes the process and application of coating metal parts with porcelain enamel to provide electrical insulation. The mechanical and vacuum testing of Marman flanges coated with porcelain and using metal Helicoflex seals to form a zero length electrical break are detailed. The use of porcelain enameled parts is attractive since it is fast, inexpensive and enviromentaly safe and most of all satisfies stringent vacuum system requirements.

VT-TuP3 High Resolution Quadrupole Mass Spectrometer for Light Masses, *A. Hofmänner, N. Müller,* ***H. Eppler,*** Balzers Instruments, Principality of Liechtenstein

Nuclear fusion experiments are performed with gas mixtures containing several components of low mass number (H2, D2, T2, 3He, 4He etc.). Quadrupole mass spectrometers with unit resolution can not separate these gases because of spectral overlaps even if spectrum- deconvolution algorithms are used. So high resolution mass spectrometry is required to separate the components with identical nominal mass numbers. For high resolution measurements in the low mass range a radiofrequeny-generator was developed that operates in the second Mathieu stability region. It drives a 16 mm rod diameter, 300 mm long mass filter at a frequency of 2.05 MHz and covers the mass range from 0.4 to 16.4 m/e. A cross- beam ion source with magnets produces ions with very good definition of ionization volume and energy. The deflection of the ions by 90Â° onto an off-axis SEM acts as an energy filter and so improves the resolution of the system. For example resolution of >400 at m/e= 4 is obtained with selectable resolution from 0.008 to 0.050 m/e at 10% peak height. The good stability of the mass scale allows for long term measurements without readjustment.

VT-TuP4 The Measurement of Multi-Layer Insulation (MLI) Outgassing and its Impact on Effective Cryostat Pumping, ***R.J. Todd***, *D. Weiss, D.J. Pate,* Brookhaven National Laboratory*; R. Davis,* Brookhaven National Laboratory, U.S.

The Relativistic Heavy Ion Collider (RHIC) is a superconducting particle collider that operates at cryogenic temperatures. The magnets used to bend and focus the beam are housed in twelve, 480 meter long, common cryostats. Outgassing rates of the MLI (multi-layer insulation) used in the cryostats were measured. Both the double aluminized mylar and polyester spacer material were tested for outgassing spectra and total quantity outgassed. To achieve a satisfactory base pressure in the cryostat, pumpdown estimates were made using the outgassing data. The number and size of pumps were varied to compare the effect on base pressure and water vapor loading of the pumps. Actual pumpdown curves were measured and compared with estimates. The effects of water vapor loading were also studied.

VT-TuP5 New-type Leak Detector utilizing Oxygen-Ion Conductor (I) -- Principle and Fundamental Performances--, ***K. Tatenuma***, *K. Uchida, K. Uta, T. Noguchi,* KAKEN Co., Japan*; H. Saeki,* Japan Synchrotron Radiation Research Institute, Japan*; A. Ando,* Himeji Institute of Technology, Japan*; T. Momose,* Miyagi National College of Technology, Japan

We developed a new-type leak-detector [LeakD] with an extraordinary wide pressure range by electrochemical measurement of a partial oxygen pressure utilizing the character and performance of oxygen-ion conducting ceramics, e.g. Yttria Stabilized Zirconia (YSZ). Tests using a vacuum apparatus composed of LeakD, a residual gas analyzer (RGA), a capacitance manometer, a Penning gauge, and a turbomolecular pump, confirmed that the responces of LeakD follows Nernst's law; e.m.f.=RT/nF[ln(P(O@sub 2@)ref/P(O@sub 2@)vac)], where e.m.f.: electromotive force (V), R: gas constant (8.314 J/molxK), T: temperature of probe (K), n: charge number of ionization (4: 2O@super 2-@), F: Faraday constant (9.65x10@super 4@ C/mol), P(O@sub 2@)ref and P(O@sub 2@)vac are oxygen partial pressures at a standard gas and a vacuum, respectively. An oxygen partial pressure in a vacuum is decided from e.m.f. LeakD is simple and small, which composed of YSZ ceramics tube (od.10 mm x id.7 mm x 90 mm (long), sealed at one ended) with porous platinum electrodes on inner and outer surfaces, a heater inserted into the YSZ tube to gain a high oxygen-ion conducting rate, a thermocouple, and two electric wires to measure the e.m.f. between two electrodes. To look for a leak point using LeakD, a gas excluded oxygen, e.g. nitrogen and so on, is blown to a point. LeakD is basically a general oxygen sensor using an oxygen-ion conductor. LeakD can detect a partial oxygen pressure by a function in the ranges from 10@super +2@ to 10@super -20@ atm or less; especially it has detectable leak rate both larger and smaller than He leak rate of RGA.

VT-TuP6 A Unique Cryogenic Pumping System for Space Simulation Chambers, ***A.D. Ketsdever***, Air Force Research Laboratory*; F.M. Lutfy, E.P. Muntz,* University of Southern California

To investigate the behavior of spacecraft interactions with the space environment and their own ambient atmosphere (caused by material outgassing or propulsive maneuvering), extremely low chamber background pressures and low backscattering rates from chamber walls are required. For meaningful spacecraft-thruster interaction studies, large pumping rates are also required to maintain background pressures at acceptable levels with high propellant flow rates. For the pumping rates required by some applications, cryogenic pumping appears to be the only adequate choice. In order to have a manageable chamber size, a unique geometrical configuration for the cryogenic pumping system was developed. The pumping system consists of outer liquid nitrogen panels which reduces the heat transfer from the outer chamber walls (300 K) to the inner gaseous helium panels (20 K). The inner cryogenic arrays consist of many radial fins which serve several purposes. First, the fin arrangement increases the available pumping surface area by an order of magnitude over a simple cylindrical geometry. Second, there are gaps between the radial fins which allow heavy ions and radiant heat to impact the graphite covered liquid nitrogen panels. In this way, sputtering from energetic ions is reduced and the liquid nitrogen panels remove most of the heat generated by the thruster. Finally, the fins reduce the solid angle for backscattering from non-condensing chamber surfaces to a particular area of interest. With this configuration, a total chamber pumping scheme has been adopted which uses all of the interior chamber surfaces to condense gases thus reducing backscattered molecules as much as possible.

VT-TuP7 Investigation for Pumping Speed and Foreline Performance of a Turbo Booster Pump, ***R.-Y. Jou,*** Precision Instrument Development Center,Taiwan, ROC, Taiwan, ROC

A compound or hybrid turbo pump constructed by both of turbo blade and drag pumping elements is usually designed to get the best attributes of both types of pump at the same time. However, the complexities in rotor geometry incur problems for specific applications. A rotor configuration design for the new turbo booster pump which is combined a TMP section with a spiral groove rotor by a specially designed connecting blade and is successfully predicted by both of CFD and DSMC simulation methodologies has been conducted. The predicted and testing results show that this pump is effective to operate in an inlet pressure range from 10-7Torr to around 10Torr with a maximum pumping speed appropriately 1000L/s in free molecular regime. Modern semiconductor processes require a large gas throughput and an ultrahigh vacuum (UHV) pump to create an ultraclean process environment. And to choice a proper foreline pump with effective foreline capabilities to reduce contamination to process chambers is an important consideration issue for pump designs and applications.

Therefore, it is imperative to investigate the foreline performance of this pump to optimize its function. In this article, a testing system designed to measure the pumping speeds and the foreline capabilities of this pump is constructed. A conductance valve is attached between the turbo booster pump and the foreline pumps to study the optimum foreline speed for this new pump. By controlling valve conductance between HV pump and foreline pump, and by measuring the variations of pressures and throughput at inlet and outlet, the influences of foreline's speed upon the total performance of turbo booster pump are explored. Besides, to reduce cost of the mechanical booster pump and inherently danger of contamination from it, the substitution possibility using this new pump is also discussed.

VT-TuP8 True and Measured Outgassing Rates of a Vacuum Chamber of a Reversibly Adsorbed Phase, ***K. Akaishi***, National Institute for Fusion Science, Japan; *M. Nakasuga,* Kyoto University, Japan; *Y. Funato,* Suzuka National College of Technology, Japan

We reported before that the outgassing rates measured in a 304 stainless steel chamber were dependent on pumping speed. So a pump down model based on the Temkin adsorption isotherm was constructed to explain theoretically the dependence of the measured outgassing rate on pumping speed. From the model an outgassing equation was derived, which describes the change of coverage of adsorbed molecules at the wall surface of the chamber with time. Two terms, true and measured outgassing rates of the vacuum chamber, appear in the equation, and it is shown that the true outgassing rate is proportional to the measred outgassing rate and the proportional constant reveals a reduction coefficient for the pumping speed of a vacuum pump. In this paper the magnitudes of the measured outgassing rates as a solution of the outgassing equation are estimated numerically as a function of pumping speed and compared to the measured outgassing data in experiment. A good agreement between theory and experiment for the measured outgassing rates is found.

VT-TuP9 A Vacuum Gauge System with a Self-compensator for Photoelectrons Produced in the SPring-8 Storage Ring, ***H. Saeki***, Japan Synchrotron Radiation Research Institute, Japan; *T. Momose,* Miyagi National College of Technology, Japan; *H. Yonehara,* Japan Synchrotron Radiation Research Institute, Japan

Some of the Bayard-Alpert gauges mounted on crotch chambers in the SPring-8 storage ring have indicated negative pressures at stored electron beam currents more than 5 mA. Simple measurements determined that negative and lower pressure indications of the vacuum gauges were caused by an influx of photoelectrons to the collectors. Therefore, to measure pressure more accurately in such a hot-vacuum environment, we proposed a vacuum gauge system with a self-compensator for photoelectrons from the environment. The gauge has a correcting electrode which only detects photoelectron current from the environment and obtains the actual pressure by compensating the current detected in the primary collector of the gauge. The estimated actual pressure of the gauge system with a self-compensator is adequate, compared with the apparent pressure detected with Extractor gauges. To make sure of the estimation, the new gauge system will be evaluated with an experimental vacuum chamber which makes such a hot-vacuum environment using an electron gun.

VT-TuP11 Study of Microgeometry of Activated Coals and Non-evaporable Getters, *S.B. Nesterov, Yu.K. Vassiliev,* Moscow Power Engineering Institute, Russia; ***G.L. Saksaganski***, The Efremov Research Institute of Electrophysica Apparatus, Russia

Determination of the pumping speed is of crucial importance by design of the surface action pumps. Pumping speed depends on the sticking coefficient value. Dependence of the integral sticking coefficient for the whole cryopanel on the local sticking coefficient in the concrete point is being determined in this paper. Real surface of the sorbent is not flat. So a molecule of the pumped gas can be reflected from this surface several times. The real surface of different sorbents - activated coals and non-evaporable getters is analysed by scanning tunnel microscope. To calculate dependence of the cryopanel integral sticking coefficient on the local sticking coefficient on the sorbent surface the test particle Monte-Carlo method is used considering the real surface of a sorbent. Integral coefficient values obtained during the experiment allow one to compute the local coefficient value for the concrete sorbent type. Obtained results for various types of sorbents may be useful for engineers constructors of surface action pumps.

VT-TuP12 RHIC Turbomolecular Pumping System, ***D. Weiss***, *R.C. Lee, D.J. Pate, L.A. Smart, D. Zigrosser,* Brookhaven National Laboratory

The Relativistic Heavy Ion Collider (RHIC) Project at Brookhaven National Laboratory (BNL), is a 3.8 km circumference collider commissioned earlier this year. The superconducting magnets used to steer and focus the ion beams, operate at 4.2K, and are contained in 28 cryostats of various sizes. A network of turbomolecular pumping stations (TMPS) is employed to maintain the rough vacuum in the magnet cryostats prior to cooldown of the machine, and to pump helium, which may be present in the cryostats due to leaks in the internal cryogenic distribution system. The design and operation of the TMPS and TMPS network is presented, with particular focus on the integration of off-the-shelf components with the BNL custom designed station logic controller (SLC). Additionally, the performance of the TMPS during the commissioning phase of RHIC is described.

VT-TuP13 Photon Stimulated Desorption Measurements of Copper Beam Chambers for the KEKB Collider@Footnote 1@, ***C.L. Foerster***, *C. Lanni,* Brookhaven National Laboratory; *K. Kanazawa,* KEK, Japan; *K. Shimotsuma,* KSA Inc.

KEKB is an asymmetrical collider constructed for the High Energy Accelerator Research Organization(KEK) in Ibaraki, Japan. The new collider utilizes two UHV ring chambers, one for a 3.5 GeV positron beam and the other for an 8 GeV electron beam, to study B-mesons. Two Samples, each one (1) meter long, of KEKB beam chambers were studied on newly constructed beamline U9a at the National Synchrotron Light Source (NSLS). Copper was chosen by KEK for the chamber construction material as it withstands high peak heat loads and also serves as a radiation shield. The samples have a circular cross section of 94mm inner diameter. After cleaning, flanges were electron-beam welded to the ends of the samples, and then the assembly was shipped to the NSLS, for installation in the PSD set up. Once sucessfully leak tested, the sample was installed in U9a, exposed to more than 10@super 23@ photons direct from the source at a critical energy of 595 eV, striking the sample at an incident angle of 100mrad. The major PSD yields for hydrogen, carbon monoxide, carbon dioxide, methane, and water vapor are reported as a funtion of accumulated photon flux and sample preparation. The results are compared with other PSD measurements on NSLS beamlines U9a, U10b, X28a, and those of other laboratories published for copper. @FootnoteText@ @Footnote 1@ Work performed under auspices of the U.S. Department of Energy, under contract DE-AC02-76CH00016.

Vacuum Technology Division
Room 610 - Session VT-WeM

Vacuum Pumping Systems

Moderator: B.R.F. Kendall, Elvac Laboratories

8:20am **VT-WeM1 Affect on Pumping-Speed Measurements Due to Variations of Test Dome Design Based on Monte-Carlo Analysis**, ***S.B. Nesterov,*** *Yu.K. Vassiliev,* Moscow Power Engineering Institute, Russia*; R.C. Longsworth,* IGC-APD Cryogenics, Inc.

Test domes for measuring pumping speed are defined in AVS Standard 4.1, Pneurop Standard PN5ASRCC/5 and the last draft of the new AVS Standard for Cryopumps. These test domes are similar. They try to provide a measure of the speed of a pump as if it is mounted in the center of a large, flat plate in a large chamber. In this case, the flow distribution is diffuse while in the test dome the flow pattern has a stronger axial component. The location of the pressure gauge is intended to compensate for the different flow pattern. Certain parameters in the design of the test domes are not rigidly specified -- including the shape for the top of the dome, the diameter of the gas feed tube for the single-dome method or the orifice for the two-gauge method. A Monte-Carlo Analysis has been carried out to analyze the differences in speed which will then be measured for different configurations for the top of the test dome, different gas feed-tube diameters and different diameters of the hole in the aperature plate. Variations in the range of 2% to 3% are calcualted. In addition, a comparison of pumping speed for an APD Cryogenics Marathon 8 Cryopump mounted in a test dome vs. being mounted on a flat plate in a large chamber is presented in order to illustrate the potential affect of the cryopump geometry.

8:40am **VT-WeM2 A Highly Simplified and Reliable Means of Regenerating Closed-Loop Gaseous Helium Cryopumps**, *D.W. Crone, J. Brady, M.O. Foreman,* Ebara Technologies Inc.*;* ***K.M. Welch,*** Consultant

A unique means of regenerating closed-loop, gaseous helium refrigerator cryopumps is reported. If one reverses the rotation of the expander motor of a Gifford-McMahon refrigerator, the thermodynamic cycle is reversed and heat rather than refrigeration is produced at the expander cooling stations. The heat input stemming from reversing the thermodynamic cycle may be used in a controlled manner to achieve a simple, safe and effective regeneration cycle of the cryopump. This reverse cycle regeneration process, and its effectiveness and reliability will be described.

9:00am **VT-WeM3 Review of Pumping by Thermal Molecular Pressure**, ***J.P. Hobson,*** National Vacuum Technologies Inc., Canada*; D.B. Salzman,* Polychip Inc. **INVITED**

Pumping energy is supplied by temperature changes only. A general feature of such pumps is that the upper pressure limit is reached when the mean free path becomes small relative to the physical dimensions of the pump in the region of the temperature transition. Thus the upper pressure limit of these pumps has been determined by the microfabrication technology of the day; they have operated at relatively low pressures, with low throughputs, and have not become main-line pumps. In recent years, however, MEMS (Micro-Electronic-Mechanical Systems) has introduced a whole new level of miniaturization to devices in general, including vacuum devices, and hence has raised the upper pressure limits, and thus the throughputs, of thermal molecular pumps to near atmospheric levels.@footnote 1@ The purpose of this paper is to review various physical manifestations of pumps using thermal molecular pressure, which have been realized over the years. Emphasis is placed on pumps which have actually been constructed and tested. The general pumping phenomenon has had various names: the Knudsen compressor, thermal transpiration, thermal creep, thermodynamic, thermomolecular, thermal molecular, and accommodation pumping. This multiplicity of names can cause some confusion and it is one of the objectives of this review to simplify this situation. We have chosen to title the paper "Review of Pumping by Thermal Molecular Pressure", following the terminology used by Knudsen.@footnote 2@ It is found that, broadly speaking, these pumps divide into two classes: (a) those using no explicit surface treatment; and (b) those using specially prepared surfaces. It is further found that pumps in class (a) have both an upper and lower bound in pressure, while pumps in class (b) have only an upper bound in pressure. A Table is assembled comparing experimental results of pumps which have actually been built and tested. However, scaling rules for multiple stage pumps, based on results obtained for single stage pumps are presented. Despite their diversity thermal molecular pumps all have the compelling advantage that there are no moving parts, nor any fluids, in the vacuum. @FootnoteText@ @footnote 1@ S.E.Vargo, E.P.Muntz, G.R.Shifflet, and W.C.Tang, J. Vac. Technol. A, (in press). Paper presented at the 45th International Symposium of the American Vacuum Society, Baltimore, 1998. @footnote 2@ M.Knudsen, "The Kinetic Theory of Gases", Methuen's Monographs on Physical Subjects, John Wiley and Sons Inc., New York, 1934.

9:40am **VT-WeM5 Inner Pressure Measurement of Turbo Molecular Pump**, ***H.-P. Cheng,*** *R.-Y. Jou, J.-C. Lin, F.-Z. Chen, Y.-W. Chang,* Precision Instrument Development Center, National Science Council, Taiwan, ROC

In the past decades, a lot of papers have been published to deal with the pumping mechanism of turbo molecular pump. These articles contain theoretical and experimental investigations. But there are only few of articles contain the experimental data can supply to the comparison with the theoretical models. Most of previous experimental works devoted on the measurement of pumping speed and compression ratio of one stage turbo blade structure or one whole pump. The foregoing review shows that no related work has been published to measure the pressure variation of inner pump from inlet to outlet ports. In this study, the inner pressure measurement of a new type turbo molecular pump is investigated. The pump is developed by the cooperation of Kashiyama Industries Ltd. and Precision Instrument Development Center with a desire to replace the mechanical booster pump. The experimental measurement is followed by the Japan standard JVIS-005. The flow meter method is adopted here. In order to measure the pressure variation from pump inlet to outlet, there are 9 holes with 6.5-mm inner diameter are drilled through the casing of pump along the axial direction. The distances of 9 holes from the plane of inlet port are 49.5, 79.5, 107, 127, 147, 167, 187, 207, and 227 mm. The metal gasket face seal fittings with inner diameter 3-mm are welded into the holes by TIG-Tungsten inert gas welding method. The vacuum gauges with the range of 1.E-4 to 10 torr are linked with metal gasket face seal fittings by the metal bellow tube. Six sets of inlet pressures with 1.E-4, 1.E-3, 1.E-2, 0.1, 0.5 and 1 torr are measured. The pressure variations along the axial direction are plotted versus normalized axial distance. The pressure tendency related to rotor shaped is discussed. Tendency of pressure variation of measurement and prediction is compared.

10:00am **VT-WeM6 Measurement of Axial Pressure Distribution on a Rotor of a Helical Grooved Molecular Drag Pump**, ***T. Sawada,*** *W. Sugiyama,* Akita University, Japan*; K. Takano,* Mitsui Zosen Ltd., Japan

The theory in regard to the pumping performance of a helical grooved molecular drag pump proposed by the authors has been employed successfully as a design and evaluation tool. However, some researchers presented results different from the authors' using direct simulation Monte Carlo method. Their method included the inlet effect and the secondary flow in grooves either of which was neglected in the authors' theory. This study was planned to examine the validity of the authors' theory precisely. A helical grooved cylindrical rotor was located concentrically in a smooth sleeve. In order to obtain the pressure distribution on the rotor, several taps were installed on the sleeve along axial direction. The taps led to one side of a differential pressure gauge via valves and the upstream side of the rotor was connected to the other side of the gauge. The pressure was measured by switching the valves in turn. The measurements show that (a) the pressure in the free molecule flow regime increases exponentially from the inlet to outlet, (b) the pressure increases almost linearly from the inlet to outlet in the slip and viscous flow regime, and (c) the inlet effect becomes remarkable in the turbulent flow regime. The validity of the theory has been proved from the free molecule to viscous flow regimes, but the theory needs modification so as to include the inlet effect in the turbulent flow regime.

10:20am **VT-WeM7 An MHD Plasma Vacuum Pump**, ***E.S. Ensberg,*** Microwave Plasma Products, Inc.

The demand for increased productivity in high vacuum plasma processing chambers calls for greater vacuum system throughput. Pump manufacturers have responded by refining turbomolecular and drag pump designs to raise speed and operating temperature limits. Plasma pumps, in a modular design with no moving parts, offer an alternative to rotating machinery for transport of large quantities of gas, especially light or inert gases. The concept depends on the Lorentz force j x B to generate a pressure gradient, directed from the inlet to the outlet of each of an array of channels. The transverse magnetic field B is provided by permanent magnets incorporated in the channel array. Microwave electric fields, parallel to B, form the plasma within the channel array. A steady electric field E, between stainless steel electrodes in each channel, drives the

transverse current density j, such that j x B is always directed from the inlet to the outlet region of each channel. Measurements of compression ratios and of throughput per channel vs. pressure (in the range 0.001 to 1 Torr) in evolving laboratory models employing these concepts are reported, together with an approach to modelling transport of plasma and neutrals in the channels.

10:40am **VT-WeM8 Stable Sputter Ion Pump Design***, **J.B. McGinn**,* FEI Company

Title: Stable Sputter Ion Pump Design Abstract: The cause of unstable leakage currents in diode sputter ion pumps (SIP) was investigated. The discharge current of diode SIP's of various designs was monitored through a testing protocol of alternate gas exposures. Discharge current instabilities were detected after gas exposures. Specific patterns of current instability were found characteristic to the gas exposure sequence and pump design parameters. Post-mortem examination revealed fields of dendritic protrusions on the cathode plates localized upon the highly ion bombarded cathode craters. Dendritic protrusion density was greatest in cathode craters adjacent to either virtual anode cells or standard cylindrical anode cells optimized for maximum current with close anode to cathode spacing. The dendritic protrusions were found to be responsible for field emission based unstable leakage currents. Various high stability diode SIP's were built and characterized. High stability was achieved through the implementation of the optimal combination of anode cell diameter, anode to cathode spacing, operating voltage and magnetic field as was found necessary to minimize the growth rate of dendritic protrusions. An ultra-high stability diode SIP was built and tested incorporating a muffin tin cathode shape in conjunction with the elimination of virtual anode cells. Single Penning cell optimization results are presented. J. B. McGinn FEI Company 7425 NW Evergreen Pkwy Hillsboro OR 97124 jbm(at)feico.com (503) 640-7580.

11:40am **VT-WeM11 Dry Vacuum Pumps for Semiconductor Processes - Guidelines for Primary Pump Selection***, **P.A. Lessard**,* Varian, Inc.

Each of the many processes used for the production of ultra-large scale integrated (ULSI) devices or flat panel displays (FPD) has its own chemical and physical requirements. Many require a vacuum environment that may range from slightly below atmospheric to ultrahigh vacuum (UHV). Requirements for system cleanliness often dictate an oil-free pumping system. This paper discusses each of the process classes which require a dry primary vacuum pump - deposition (both physical and chemical), doping and material removal - and offers guidelines for the selection of the proper pump type. There are three classes of pump needed depending on the severity of the process - clean, moderate and harsh - with escalating complexity and cost for pumps made for the harsher environments. In addition to reviewing some of the latest developments in materials and vacuum design, particular attention is paid to operating experience with the very harshest processes - dielectric deposition and metal etch.

Vacuum Technology Division
Room 610 - Session VT-WeA

Dry Pumping Systems

Moderator: K.M. Welch, Consultant

2:00pm **VT-WeA1 Dry Vacuum Pumps - A Method for the Evaluation of the Degree of Dry**, ***A.D. Chew***, *R.P. Davis, R.A. Abreu,* BOC Edwards, U.K. **INVITED**

The drive towards dry vacuum pumping has occurred across the spectrum of vacuum applications from semiconductor manufacture to industrial processing. This brings with it a need to systematically evaluate and quantify the degree of cleanliness characteristic of any particular pump; currently there is no universally accepted method to perform this function. A methodology which has been developed for repeatable measurements of pump cleanliness will be discussed. It is based on residual gas analysis under carefully controlled pump conditions. This facilitates direct comparisons of cleanliness between pumps of the same and different design. Additionally it allows for the assessment of methods introduced to improve cleanliness.

2:40pm **VT-WeA3 Ebara AAS-series Screw-type Dry Vacuum Pump**, ***Y. Watanabe***, *R. Ward,* Ebara Technologies, Incorporated **INVITED**

A new screw-type dry mechanical vacuum pump from EBARA Corporation employs two-stage main pump screws and DC brushless motors to reduce energy consumption and the resulting greenhouse gas generation. The patented Zero Theoretical Clearance screw profile permits tighter mechanical fits and increases pumping efficiency.

3:20pm **VT-WeA5 Adapting Dry Vacuum Technology to Cu CVD Effluent Abatement in Integrated Circuit Manufacturing**, ***J.R. Bottin***, *D.G. Mrotek,* Leybold Vacuum Products **INVITED**

Developments in the manufacturer of IC's are driven by the need for a higher transistor density and increased speed. The semiconductor industry is aggressively pursuing techniques that enable 0.18 µm interconnects, with the goal of 0.13 µm by 2003 or sooner. Because of its low resistivity and high electromigration resistance, copper is the metal of choice for sub-quarter micron interconnects. New development will be required for copper processes including the abatement of copper and copper by-products. Chemical vapor deposition (CVD) of copper utilizing a liquid precursor is an efficient means for depositing seed layers of copper for high aspect ratio geometry. The reaction of the liquid precursor produces Cu, Cu(hfac)@sub 2@ and TMVS, which all have unique properties that can lead to premature dry pump failure and high abatement costs. A viable, environmentally friendly solution has been developed and is comprised of an optimized dry pump, inlet reactor, cooled exhaust collector and resin bed abatement device with integrated electrical control. The inlet reactor decomposes the residual liquid precursor leaving the tool and removes elemental copper. The residual Cu(hfac)@sub 2@ and TMVS remain in the vapor phase through the vacuum pump. The mixture is then cooled in an exhaust collector where Cu(hfac)@sub 2@ is condensed prior to entering the resin bed abatement device, where the TMVS is subsequently removed. The exhaust collector has been designed as a shipping vessel to transport the collected Cu(hfac)@sub 2@ back to the manufacturer for recycle, significantly reducing abatement costs. The system goal for 99% or greater removal of each component at the exhaust of the resin bed is presently being validated through beta-site testing. With copper interconnects representing the future of IC's, it is imperative that suppliers meet the process challenge posed by the use of copper. The system described above is a critical step toward meeting the challenge of Cu CVD effluent abatement.

4:00pm **VT-WeA7 Dry Pumping**, *S. Doherty, F. Ramberg,* ***P. Annandale***, Alcatel Vacuum Products **INVITED**

There are many reasons to convert from oil sealed, or so called 'wet,' vacuum pumping systems to those where no seal fluid or lubricant is exposed to the process gas. Among these are contamination, cost, and environmental impact. With certain deposition processes this conversion presents problems related to the phase change of the material pumped and its effect upon the pump and its handling by subsequent abatement systems. Alcatel has studied and characterized several processes that presented extremely difficult challenges in the conversion from wet to dry pumping. These conversions were ultimately successful due to an understanding of material properties and reactions possible within the pump and system hardware and the correct management of pump design and application. Alcatel will present process analysis, design features, and operating data that demonstrate how such classically difficult processes may be converted from wet pumping to dry pump systems. The analysis will include phase diagrams of the materials and products of reaction for the process, conductance calculations for the piping system, and the pumping speed requirements. A survey of dry-pump design types demonstrates why the process is difficult to achieve; and an in-depth discussion of the successful design is included. Finally, the data that demonstrate not only successful pump operation but, an accounting of process material is presented. What may be concluded from the presentation is what analysis techniques are available to determine whether a process will be difficult to convert from wet to dry pumping, and methods to predict what dry pump design type will yield success. Further, we will show the relative increase in reacted and reactive material exhausted from a dry pump over that from a wet system.

4:40pm **VT-WeA9 The Dry Pump in the Industrial Market**, ***J. Scherbik***, Stokes Vacuum Inc. **INVITED**

Dry pumps have been commonly used for some time in the semi-conductor market. This article discusses the pros and cons of a dry pump in the more traditional markets such as chemical, pharmaceutical, metallurgical, and vacuum coating. Different options will be presented along with a description of ancillary equipment. Cost of ownership is compared with more traditional types of vacuum pumps. Recommendations are included for pump sizing as well as discussing applications which might benefit from dry pumps.

Vacuum Technology Division
Room 610 - Session VT-ThM

Outgassing, Leaks, and Mass Flow Controllers

Moderator: W. Weed, Sandia National Laboratories

8:20am **VT-ThM1 A Comparison of Outgassing Rates from Stainless and Carbon Steels**, ***H.F. Dylla,*** Thomas Jefferson National Accelerator Facility; *W.R. Blanchard,* Princeton University

Various types of stainless steels (ANSI type 300 series) are the most commonly used materials for the construction of high and ultrahigh vacuum vessels and associated vacuum hardware. As a result of this widespread use, numerous outgassing studies of stainless steels have been published in the literature. The available information on outgassing from carbon steels is relatively meager. Carbon steels are usually not considered for use in high vacuum systems because of the propensity for corrosion (oxidation) in ambient environments and the assumption that standard surface preparation techniques would be less effective on carbon steels in comparison to 300 series steels. During consideration of a number of vacuum applications of carbon steels we reviewed the outgassing literature and found that an often quoted measurement significantly overestimates the outgassing from properly cleaned material. We describe outgassing measurements we have performed on both types of steel in order to get a direct comparison of the materials on the same apparatus and using the same surface preparations techniques. Results show that the short-term (<100 hr) outgassing rates from clean carbon steel are only a modest factor (times two to four) larger than from similarly prepared stainless steel. The increased outgassing rate appears to be in direct proportion to the passivation oxide layer thickness. @FootnoteText@ This work was supported by US DOE Contract No. DE-AC02-76-CH-03073.

8:40am **VT-ThM2 Experiments with Thin-Walled Stainless Steel Vacuum Chamber**, ***V. Nemanic,*** Institute of Surface Engineering and Optoelectronics, Slovenia; *J. Setina,* Institute of Metals and Technology, Slovenia

The application of reasonably thin stainless steel wall was suggested recently as alternative approach in construction of UHV chambers, since the hydrogen outgassing rate can be decreased to the level required to reach UHV and EXV much easier. Experimental stainless steel chamber (AISI type 304, volume 13 l) with uniform wall thickness (0.6 mm) has been constructed. It was equipped with a miniature ion-getter (IG) pump and spinning rotor gauge (SRG) thimble. The chamber was pumped down and initially degassed by moderate bake-out (2.5h, 150 deg.C) by a turbomolecular pump system. Gas accumulation method was applied for determination of outgassing rate q@sub out@ and total amount of released gases using capacitance manometer during pump down and SRG after the chamber was sealed-off. The initial q@sub out@ at room temperature after initial degassing was in the range of q@sub out@=10@super -12@ mbar l s@super -1@cm@super -2@ with a tendency of slight decrease with time. Thermal dependence of outgassing rate was determined from SRG measurements in the temperature range from 19 to 50 deg. C over several days with ability to extract the offset value by means of IG pump. The bake-out of the chamber was repeated for 72h at 200 deg. C which lead to the decrease of outgassing rate to one tenth of the initial value. The results show the benefit of using a moderately thin wall and agree well with a model of recombination limited hydrogen outgassing from stainless steel. @FootnoteText@ B.C.Moore: Atmospheric permeation of austenitic stainless steel, J.Vac.Sci.Technol., A16(5), 3114-3118, 1998 V.Nemanic,T.Bogataj: Outgassing of a thin wall stainless steel chamber, Vacuum, 50, 3-4, 431-437, 1998

9:00am **VT-ThM3 Review of Models for the Outgassing of Water Vapor from Metallic Surfaces**, ***B.B. Dayton,*** Consultant **INVITED**

The variation of outgassing rate with pumping time for water vapor from unbaked metal surfaces has been shown by several authors to depend on the ratio of pumping speed to exposed surface area, the time of initial exposure to the atmosphere at a known humidity, the ambient temperature, the thickness and porosity of the oxide layer on the metal surface, and the pretreatment or conditioning of the surface. The outgassing behavior differs radically from that for plastics and elastomers, and many authors have attempted to explain this behavior on the basis of theoretical models for the molecular kinetics. These models will be reviewed and evaluated. The present author will suggest a new model based on rapid physical adsorption and desorption in the oxide layer, with heat of adsorption in the neighborhood of 10 kcal/mol (corresponding to two hydrogen bonds), during atmospheric exposure followed by a slower (low probability) transition from a physisorbed precursor state (with activation energy of about 5 kcal/mol corresponding to breaking of one of the hydrogen bonds) to a "weak chemisorption state'', involving rotation and wobble about the remaining single hydrogen bond until an exposed pair of electrons associated with the water molecule has been captured in the positive field of a nearby metal ion without necessarily breaking the hydrogen bond to the oxide ion. Outgassing then involves the desorption of the undissociated water molecule from this bound state to the gas phase with an energy of desorption ranging from 20 to 30 kcal/mol.

9:40am **VT-ThM5 Measuring and Locating Internal Helium Leaks in the RHIC Insulating Vacuum System**, *R. Davis,* Brookhaven National Laboratory, U.S.; *C. De La Parra,* ***H.C. Hseuh***, *P. Mickaliger, D.J. Pate,* Brookhaven National Laboratory

The Relativistic Heavy Ion Collider (RHIC) uses superconducting magnets to bend and focus the high-energy particle beams. Strings of these magnets are enclosed in insulating vacuum cryostats up to 480 meters long. The cryostat vacuum must be 10@super -5@ Torr or less to minimize heat transfer from the ambient cryostat wall to the 4K magnet cold mass. There are over 25,000 in-situ welds of internal helium lines with a total weld length over 7 km. Helium leaks greater than 10@super -5@ std.cc/sec (ambient leak rate) in these welds were located and repaired. The methods of locating these leaks in the long cryostat volumes will be described. Smaller leaks were monitored during the cool down of the magnets. The correlation of the leak rates with the helium line temperature and pressure will be presented.

10:00am **VT-ThM6 Contraflow Leak Detectors with Improved Sensitivity Under High Helium Background Conditions***, ***C. Dong,*** Old Dominion University; *G.R. Myneni,* Thomas Jefferson National Accelerator Facility; *G.A. Rooks,* Varian Vacuum Technologies

The leak detection sensitivity of the contraflow leak detectors is limited in general by its high operating pressure. Helium is known to be trapped in the fore pump of the leak detector and contributes to the large background signal particularly after leak checking large leaks (~1.0e-4 Pa. l/s). The trapped background helium can be effectively removed by purging the system with dry nitrogen. Such nitrogen purge is found to shorten the clean up period of leak detector by 90%. A novel method was developed to detect small leaks in large background helium signal. This method includes the lowering of pumping speed and adjustment of leak detector parameters such as the reduction of emission current and lowering the zero offset to minimize the background helium signal. We are able to leak check 3.0e-8 Pa. l/s and smaller leaks in a background signal of 4.0e-6 Pa. l/s of helium with 20 % accuracy. * This work was supported by U.S. DOE Contract No. DE-AC05-84ER40150 and Varian CRADA No. SURA-97-S002

10:20am **VT-ThM7 LIGO Beam Tube Component and Module Leak Testing**, ***W.A. Carpenter,*** *P.B. Shaw,* Chicago Bridge and Iron Co.; *R. Weiss,* Massachusetts Institute of Technology; *L. Jones,* California Institute of Technology

LIGO (Laser Interferometer Gravitational-wave Observatory) is a joint project of the California Institute of Technology and the Massachusetts Institute of Technology funded by the National Science Foundation. The project is designed to detect gravitational waves from astrophysical sources such as supernova and the formation of black holes. The LIGO project constructed facilities at two sites in the U.S. Each site includes two perpendicular laser beam tube lines (each 4 km long) which join at one end to form an "L" shape. The beam tube is a stainless steel, ultra high vacuum tube which will operate at a vacuum of 1 x10@super -9@ torr or better. The beam tube was manufactured using a custom spiral weld tube mill and was manufactured with special emphasis on reduced outgassing rates. The integrity of the beam tube was assured by leak testing each component of the beam tube system prior to installation and then to leak test each 2 kilometer isolatable beam tube module after completion. This paper discusses the leak detection procedures used to leak test 16 km of 1.25 m diameter UHV beam tube used in the LIGO project. The beam tube was leak tested in four steps including leak testing fabricated tube sections, local leak testing of 250 mm diameter valve and valve nozzles, leak testing circumferential welds joining tube sections together and final leak testing of the installed beam tube module. The component leak testing included 800 tube sections which were 20 m long, 808 circumferential welds and 72 valved nozzles. Each component was tested to a sensitivity of better than 1x10@super -10@ atm. cc/sec of helium. The leak test of the 2 kilometer beam tube module would have been extremely difficult and expensive

using standard helium leak detection techniques. Therefore, a method was developed utilizing a Residual Gas Analyzer (RGA) to measure the leak tightness of the two kilometer long modules. A method was also developed to utilize nine RGAs to locate any detected leaks.

10:40am **VT-ThM8 Low-flow Measurements Techniques for Calibrating Mass Flow Controllers**, ***S.A. Tison***, Millipore Corporation, U.S.A; *C. Ruppert,* Millipore Corporation

Many semiconductor processes require stable and known flow of a gas or multiple gases. Flows ranging from 100 slpm (7 x 10-2 mol/s) to 10 sccm (7 x 10-6 mol/s) are common. Primary standard flowmeters have been developed to measure these flows and are in common use.. The most common techniques include gravimetric and those based on volume displacement at constant pressure. Recently a significant number of processes are using much lower flows with flows as low as 0.1 sccm (7 x 10-8 mol/s) being required. Most of the traditional techniques for measuring gas flow are not well suited for measurements in this range. Becasue of this, process tuning and reproducability can be adversely affected by errors in the mass flow controllers which are induced by their calibration. Two of the most common instruments used for low-flow measurements , a constant volume flowmeter and a laminar flowmeter, were compared with a number of gases including nitrogen, hydrogen, and sulfur hexafluoride. The agreement of the techniques was generally within 0.5% over a range of 1 sccm (7 x 10-7 mol/s) to 10 sccm (7 x 10-6 mol/s) and somewhat worse for lower flows. The comparison data and attributes of these two types of standards is discussed.

11:00am **VT-ThM9 Dimensionless Parameters for Laminar Flowmeters**, ***R.F. Berg***, National Institute of Standards and Technology

Laminar flowmeters have strong advantages as transfer standards for measuring low flow rates of gases. Ideally, the difference between the flowmeter's entrance and exit pressures, P@sub 1@ and P@sub 2@, is that associated with viscous, creeping flow. One can then approximate the volume flow rate by the value Q@sub 0@ = @pi@R@super 4@(P@sub 1@-P@sub 2@)/(8@eta@L). This is the Hagen-Poiseuille relation which describes an incompressible fluid of viscosity @eta@ flowing through a capillary of circular cross-section with length L and radius R. In practice, the actual flow rate Q is described by the discharge coefficient C@sub d@=Q/Q@sub 0@. Achieving an accuracy of 0.1% requires a series of corrections to C@sub d@, each associated with at least one dimensionless parameter. Identifying the form of these corrections allows one to define useful dimensionless parameters. Important deviations of C@sub d@ from unity occur because the gas is compressible. A steady mass flow rate causes the volume flow rate to depend on position along the capillary. This corrects C@sub d@ by a factor proportional to (P@sub 1@+P@sub 2@). Furthermore, the additional pressure drop associated with the expanding gas adds to C@sub d@ a term proportional to the Reynolds number Re. Recent analysis of capillary viscometers by van den Berg and coworkers showed that the nonparabolic flow associated with the expanding gas increased the size of this term. Their result is used here to describe the performance of a laminar flowmeter. Dimensionless parameters incorporated in this correction include Re, the pressure ratio P@sub 2@/P@sub 1@, and the aspect ratio R/L. Other significant dimensionless parameters include the Mach number, the ratio of the gas's slip length to the capillary's radius, the Dean number characterizing centrifugal effects in a coiled capillary, and the correction terms in the gas's virial equation of state.

11:40am **VT-ThM11 Decay Rate of Photoresist Outgassing from Ion Implantation**, ***A.S. Perel***, *T.N. Horsky,* Eaton Corporation

Outgassing of hydrocarbons results from ion implantation into wafers covered with photoresist. Depending on the implant energy and current, the quantity of gas can be large and therefore high effective pumping speeds are important to minimize interference with the ion beam. We measured the time dependence of this outgassing to determine the rate that the outgassing decays. This information is relevant for design of implanter process chambers with rotating disks. The photoresist outgassing decay rate determines the geometry of the gas load, and can be used to determine pump placement and chamber design. The experiment involved a single photoresist wafer and 12 dummy wafers on a 13 pad disk. By measuring the collector current directly from the ion gauges we were able to time-resolve pressure measurements to better than 1 ms. Two pressure pulses were measured, the pulse that results from the implant and a pulse that results from the outgassing wafer passing the gauge. The relative difference in amplitude and time, as observed from two gauges, were used to calculate the outgassing decay rate. We reduce several data sets collected at different disk rotational speeds to fit a candidate model for the time-dependence and mechanism of photoresist outgassing.

The Science of Micro-Electro-Mechanical Systems Topical Conference

Room 620 - Session MM+VT-ThA

Vacuum MEMS

Moderator: C.C. Wong, Sandia National Laboratories

2:40pm **MM+VT-ThA3 Quadrupole Mass Spectrometry using MEMS**, ***S. Taylor,*** University of Liverpool, U.K., UK **INVITED**

Quadrupole Mass Spectrometers (QMS) find a wide range of applications worldwide. The conventional QMS arrangement uses circular metallic rods as the mass filter excited electrically at voltages up to 1kV depending upon the application. If the size and voltages can be reduced then the range of applications for QMS instruments would increase. The application of MEMS technology allows the fabrication of submillimetre versions of such structures. In this paper the development of a miniature QMS is reported in which the conventional rod arrangement has been replaced with a microengineered version. The structure is made in silicon with metallised specially drawn glass fibres of length 20-30 mm and diameter 0.5 mm to act as the quadrupole rods. The correct electrode spacing and alignment are achieved through the use of V-shaped grooves etched into the silicon. This is about one order of magnitude smaller than most conventional QMS filters, with the potential for further reduction in size. The MEMS mass filter was mounted onto a commercial ion source, which was in turn attached to a vacuum flange and supplied by an electronic drive circuit modified to run at 6MHz. Mass spectra in the range 0-50 a.m.u were obtained and these were simulated numerically. The results indicate a linear mass scale with 5-10% valley separation between O2/N2 peaks and a best resolution at 10% peak height of around 2 a.m.u at mass 40. Reliable QMS operation was obtained up to pressures in the 1E-4 to 1E-3 mbar range and the highest operating pressure was felt to be a limitation of the ion source, rather than the mass filter.

3:20pm **MM+VT-ThA5 Miniaturizing an Ultra-High Vacuum Orbitron Pump**, ***J.Z. Wilcox***, *J. Feldman, T. George,* JPL-Caltech*; M. Wilcox, A. Scherer,* Caltech

NASA has identified the development of miniature vacuum pumps as a key future technology need. Miniature pumps will be needed for miniature instrument applications such as mass spectrometers and electron microscopes. Traditional pumps cannot be flown on microspacecraft due to their size, mass, and power requirements. This talk will discuss a novel approach towards the miniaturization of a particular type of high vacuum pump, known as the "Orbitron" pump. The Orbitron pump is an ion-getter pump that does not require magnetic confinement of the ionizing electrons. The purely electrostatic operation, coupled with a novel ring anode design under the development at JPL, enables miniaturization of the orbitron pump to sub-centimeter dimensions, and in addition may allow integration with instruments for in situ planetary exploration such as the Atmospheric Electron X-ray Spectrometer. The pumping action of the Orbitron pump is based on ionization of gas molecules by externally injected electrons which are trapped into stable helical orbits in a cylindrically symmetric electrostatic field around a positively charged anode. The ionized molecules are accelerated to the cathode and embedded in the surrounding collector. However, the conventional linear anode design does not lend itself to miniaturization very well since a minimum length of anode is required to establish stable orbits. The end losses are circumvented in the ring anode design, and in addition the "planar" geometry of the ring orbitron lends itself to miniaturization as well as ease in interfacing with other micro-instruments such as mass spectrometers, electron microprobes and electron microscopes. The goal of our effort has been to verify the feasibility and scalability of the proposed pump design. We will discuss the results of the validation experiments and modeling, impact on scaling to sub-centimeter dimensions, and compare the results with similar results for the linear anode orbitron.

3:40pm **MM+VT-ThA6 Scaling and Microfabricating a Low-Pressure Inductively Coupled Plasma Source**, *Y. Yin,* ***J. Hopwood,*** Northeastern University

Plasmas are commonly used in many large-scale systems. For example, chemical analysis using optical emission spectroscopy relies on gaseous plasmas to electronically excite the sample. Plasmas are also used as sources of radicals and ions for materials modification and for ion propulsion. In this presentation we will describe the miniaturization of plasma sources to dimensions that are compatible with MEMS. One of the most robust methods of generating a plasma is by inductively coupling an rf field to a low-pressure gas. Inductively coupled plasmas (ICPs) can operate for extended periods in reactive gas environments because ICPs are electrodeless. In addition, the geometry of the impressed rf field creates a high density of electrons with relatively low power consumption. A large-scale planar ICP uses a 10 to 30-cm spiral-shaped coil adjacent to a dielectric vacuum window; this geometry is particularly well-suited to microfabrication as the source is scaled down to dimensions the order of 1 mm. The scaling laws associated with miniaturization have been experimentally investigated in terms of optimum frequency of operation and gas pressure. In addition, the effects of scaling the dimensions on plasma properties such as electron temperature and electron density are also measured and modeled. The decreased dimensions of the coil reduces the inductance of the coil and necessitates a higher frequency of operation. Large scale ICPs typically operate at 13.56 MHz, but 5 mm ICPs function most efficiently at 300-400 MHz. Of particular importance is fabricating a coil with a high quality factor (Q) at the operating frequency. The optimum pressure for initiating the plasma is found to scale with the operating frequency such that the electron-neutral collision frequency equals the power supply frequency. Finally, the plasma sheath, or dark space, does not scale with the source dimensions. This appears to set a lower limit on the physical dimensions of the plasma source.

4:00pm **MM+VT-ThA7 Design and Fabrication of an Electromagnetically Driven Microvalve for Micro Total Analysis Systems**, ***M. Shoji,*** *K. Yanagisawa, M. Hirano,* Nippon Telegraph and Telephone Corporation, Japan*; S. Nakano,* NTT Advanced Technologies Corporation, Japan

Microvalves that control fluid flow over a wide flow rate range, and that are compactly assembled, are in great demand for µTAS, such as micro gas chromatographs. This paper reports on design considerations concerning the electromagnetic actuation and the fabrication of a microvalve that operates at a pressure difference of more than 1 x 10@super 5@ Pa with very low leakage. The valve is fabricated using silicon micromachining techniques.@footnote1,2@ The target specifications are a maximum flow rate of 10@super -1@ Pa m@super3@ s@super -1@, a leak rate of 10@super -9@ Pa m@super 3@ s@super -1@, a maximum power consumption of less than 0.1 W at a pressure difference of 10@super 5@ Pa, and a size of 4 x 4 x 2 mm including the actuation unit. The microvalve has a disk-shaped 1-µm-thick cap with a diameter of 100 µm. Actuation of the valve requires a force of more than 1.5 mN perpendicular to the surface of the cap and a stroke of 5-10 µm. To achieve this actuation, ferromagnetic material is deposited (electroplated) onto the cap and an electromagnet (1.3 x 1.5 x 3.2 mm) is set above the cap to generate an attractive force on the ferromagnetic material. The design parameters were determined by three-dimensional numerical analysis that took account of the nonlinear B-H curves of magnetic materials. When the deposited material was Ni with a thickness of 100 µm, and the distance from the Ni to the magnet was 20 µm, a sufficient force was attained if the formed Ni area was several times larger than the cap area. The analysis also showed that using materials with a higher saturation magnetization than Ni would increase the force, thus enabling the valve to work at a higher pressure difference. The effects of such materials will also be reported. @FootnoteText@ @footnote1@K. Yanagisawa, H. Kuwano, and A. Tago, Microsystem Technologies 2, 22 (1995). @footnote2@M. Hirano, K. Yanagisawa, H. Kuwano, and S. Nakano, Proc. IEEE Micro Electro Mechanical Systems, p. 323 (1997).

4:20pm **MM+VT-ThA8 MEMS Micro-Valve for Space Applications**, ***I. Chakraborty,*** *W.C. Tang, D.P. Bame, T.K. Tang,* Jet Propulsion Laboratory

We report on the development of a Micro-Electro-Mechanical (MEMS) valve that is designed to meet the rigorous performance requirements for a variety of space applications, such as micro-propulsion, in-situ chemical analysis of other planets, or micro-fluidics experiments in micro-gravity. These systems often require very small yet reliable silicon valves with extremely low leak rates and long shelf lives. Also, they must survive the perils of space travel, which include unstoppable radiation, monumental shock and vibration forces, extreme variations in temperature. Currently, no commercial MEMS valve meets these requirements. We at JPL have developed a piezoelectric MEMS valve which attempts to address the unique problem of space. We begin with proven configurations which may seem familiar. However, we have implemented some major design innovations which should produce a superior valve. The JPL micro-valve is expected to have an extremely low leak rate, little susceptibility to shock, vibration or radiation, as well as a wide operational temperature range.

4:40pm **MM+VT-ThA9 Compact Fiber-Optic Pressure Sensors Using Microfabricated Sensing Membranes**, ***Y.C. Cho,*** NASA Ames Research Center*; T. George, J. Tamayo,* Jet Propulsion Laboratory

Fiber optic sensors are inherently immune to electromagnetic noise, and are very sensitive, light weight, and highly flexible. A prototype optically-detected pressure sensor was successfully designed, assembled and tested. The sensing technique employed was fiber- optic Fabry-Perot interferometry. The sensing head is composed of an optical fiber terminated in a miniature ferrule with a thin, silicon-microfabricated diaphragm mounted on it. The optical fiber is a single mode fiber with a core diameter of 8 microns, with the cleaved end positioned 50 microns from the diaphragm surface. The diaphragm is made up of a 1.5 mm square, 0.2 mm thick silicon nitride membrane whose inner surface is metallized with layers of 30 nm titanium, 30 nm platinum, and 200 nm gold for efficient reflection. The measured differential pressure tolerance of this diaphragm is more than 1 bar, yielding a dynamic range of more than 100 dB. Preliminary tests have demonstrated excellent performance for this sensor. Sensitivity measurements of the sensor were compared with that for a 3 mm diameter B&K microphone and were found to be 2 to 4 dB better than the B&K microphone. This sensitivity is better than any existing fiber optic pressure sensor by at least three orders of magnitude. The frequency response of the fiber-optic microphone was steady and uniform within the 100 to 5,000 Hertz design frequency. The compact size and light weight of these sensors gives them several advantages. For measurement of air flows over flight surfaces, the flow-sensor interaction is smaller, providing more accurate measurements of dynamic pressure. Additionally, their small size could allow these sensors to be placed non-destructively on flight surfaces in contrast to present techniques. The fiber optic microphone also has the added advantage of high temperature tolerance, and a solid state preamplifier as in the case of the condenser microphone is not required.

Vacuum Technology Division
Room 610 - Session VT-FrM

Vacuum Systems, Design, and Engineering

Moderator: L.A. Smart, Brookhaven National Laboratory

8:20am **VT-FrM1 Electron-Cloud-Induced Effects in the APS Storage Ring***, ***R.A. Rosenberg**, K.C. Harkay,* Argonne National Laboratory

Synchrotron radiation interacting with the vacuum chamber walls in a storage ring produces photoelectrons that can be accelerated by the beam and scatter from the walls, producing secondary electrons. If the secondary-electron yield (SEY) coefficient of the wall material is greater than one, the electron intensity can be amplified (termed "multipactoring") and a runaway condition can develop. This "electron cloud" can degrade the stored beam through direct interaction or by electron-stimulated desorption of gases from the chamber walls. The energy and intensity of the electron cloud is strongly dependent on both the amount of charge in each bunch of the stored beam and their temporal distribution. In order to obtain direct evidence of the properties of the electron cloud, a special aluminum (SEY > 1) vacuum chamber was built and inserted into the Advanced Photon Source (APS) storage ring. The chamber contains ten rudimentary electron-energy analyzers. Measurements to date have shown that the intensity and electron energy distribution are highly dependent on the temporal spacing between adjacent positron bunches and the amount of current contained in each bunch. Dramatic increases in pressure are observed when the temporal distribution and intensity of the bunches are configured to maximize multipactoring. Results of measurements of the electron energy distribution and concurrent pressure will be presented and discussed in terms of models of the electron cloud. *The submitted manuscript has been created by the University of Chicago as Operator of Argonne National Laboratory ("Argonne") under Contract No. W-31-109-ENG-38 with the U.S. Department of Energy. The U.S. Government retains for itself, and others acting on its behalf, a paid-up, nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

8:40am **VT-FrM2 Vacuum Simulation of Linac Components to Optimize Pump Designs***, ***L.S. Tung**,* Lawrence Livermore National Laboratory, US*; P. Shoaff, S. Shen,* Lawrence Livermore National Laboratory

Methods have been developed to model the pressure history in linear accelerator components using Mathematica@footnote 1@ and Mathcad.@footnote 2@ The components are divided into sub-volumes represented as a lumped volume at a point in space. These sub-volumes are separated by conductances. The pressure distribution is obtained by solving the gas load equations for each sub-volume simultaneously for each time during pumpdown to the base pressure. Our models include the pressure dependence of speeds for all the system pumps as determined by a numerical fit to graphs provided by the vendor. Also included is the time-dependent outgassing history of oven-brazed copper based on recent rf cavity experiments and textbook data. Additionally, cryogenic pumping effects have been integrated into the modeling of the vacuum response in a superconducting linac structure. With these models, we can optimize the manifold design and pumping configurations. Our approach is especially useful for extrapolating costs for a large-scale linac. @FootnoteText@ *Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48. @footnote 1@Mathematica software by Wolfram. @footnote 2@Mathcad software by Math Soft.

9:00am **VT-FrM3 Experiences on the Preparation and Assembly of The Superconducting Linear Accelerator for the TESLA Test Facility**, ***A. Matheisen**,* TESLA Collaboration, DESY, Germany **INVITED**

A description of the superconducting TESLA Test Facility Linear Accelerator, which is under installation at DESY by the TESLA collaboration and of the planed VUV FEL user facility will be given. We report on the infrastructure and technologies for preparation of accelerator components. Detailed information on the preparation sequences for cavities and the connected UHV beam-line equipment under cleanroom conditions of class 10 ASTM quality will be given. Experiences in handling, preparation and the efforts in quality control of components with the need of minimum contamination by particulates to reach acceleration gradients of above 25 MV/m will presented. @FootnoteText@ *TESLA Collaboration: Armenia: Yerevan Pysics Institue, P.R.China: IHEP Beijing, Tsinghua Univ. Beijing, Finland: Inst. of Physics Helsinki, France: CEA/DSM Saclay, IN2P3 Orsay, Germany: May Born Inst. Berlin, DESY Hamburg/ Zeuthen, Univ. Wuppertal, Univers. Hamburg, Univ. Frankfurt, GKSS Geesthacht, FZ Karlsruhe, TU Darmstadt, TU Berlin, TU Dresden, RWTH Aachen, Univ. Rostock. Italy: INFN Frascati, INFN Legnaro, INFN Milano, INFN Roma II, Poland: Polish Acad. of science, Univ. Warsaw, INP Cracow, Univ. of Mining &Metallurgy, polish Atomic Energy Agency Energy Agency, Soltan Inst. for Nuclear Studies, Russia: JINR Dubna, IHEP Portvino, INP Novosibirsk, INR Troitsk, USA Argonne National Lab. Cornell Univ., FNAL, UCLA

9:40am **VT-FrM5 APT LEDA CCDTL "HOT MODEL" Vacuum System**, ***T.J. Whelan**,* AlliedSignal Federal Manufacturing and Technologies*; P.O. Leslie,* Los Alamos National Laboratory

The vacuum system for the APT/LEDA/CCDTL (Accelerator Production of Tritium/ Low Energy Demonstration Accelerator/Coupled-Cavity Drift Tube Linac) Hot Model has been installed and is currently operating at Los Alamos National Laboratory (LANL). The Hot Model has been built to test a new concept in accelerator technology. The vacuum system was designed and partially assembled and then shipped to LANL for final assembly and installation on the APT/LEDA/CCDTL. The system was designed for both flexibility and low cost. Simple outgassing and conduction models were used to predict pumping needs. This design contains almost no custom parts, which allows for quick and inexpensive changes as needed. The system consists of three pumping stages: roughing, turbomolecular, and ion and utilizes all four of the available ports on the Hot Model. This has allowed the system to reach a better level of vacuum than the originally anticipated need. @FootnoteText@ Work performed at AlliedSignal FM&T which is Operated for the United States Department of Energy under Contract No. DE-ACO4-76-DP00613.

10:00am **VT-FrM6 DA@PHI@NE Vacuum System**, ***A. Clozza**, V. Chimenti, C. Vaccarezza,* Istituto Nazionale di Fisica Nucleare, Italy

A 510 MeV high luminosity @PHI@-factory is operating at INFN Fascati National Laboratory, Italy. The accelerator complex consists of a full energy Linac, a small damping ring and a double electron-positron high current storage ring. We describe in the following the main rings vacuum system. The design is based on the requirement of 1x10@super -9@ mbar as dynamic pressure with a gas load of about 1x10@super -4@ mbar l/s per ring. The main features of the vacuum system are: all metal aluminum vacuum chamber with proper surface finishing; special alloy bolt set; monolithic water cooled copper synchrotron light absorbers; high capacity titanium sublimation pumps; lumped and distributed sputter ion pumps and high capacity non evaporable getter pumps.

10:20am **VT-FrM7 Thin-walled Vacuum Chambers of Austenitic Stainless Steel**, ***B.C. Moore**,* Consultant

It is proposed, and recommended, that vacuum chambers and systems to be built of austenitic stainless steel should be designed for the thinnest walls possible, consistent with structural integrity under atmospheric pressure. The reason for this design goal is to greatly reduce the time, effort and cost needed to outgas the chambers to reach the desired and specified vacuum level. Of course, this is directly contrary to the universally accepted concern with permeation of atmospheric hydrogen. This concern has recently been shown to be greatly exaggerated. Atmospheric permeation is at least 100 times less than previously estimated, and is possibly non-existent. Errors in the previous estimate will be briefly summarized. Published outgassing of two relatively thin-walled chambers will be discussed. Methods to predict the hydrogen outgassing rates for specific wall thicknesses and bakeout procedure will be given. Vacuum oven bakes result in a flat, uniform atomic hydrogen concentration profile within the wall and give clean, unoxidized surfaces; the instantaneous outgassing rate is directly proportional to the hydrogen recombination coefficient (at the bake temperature), and to the hydrogen concentration level, while the time required for this rate to decay varies linearly with the wall thickness. In contrast, an 'in situ' bake, with atmosphere on one side and vacuum on the opposite side of the wall, results in an asymmetric concentration profile, with a minimum on the atmospheric side and a maximum on the vacuum side. To further confuse the issue, room temperature operation also causes an asymmetric concentration profile, but in the opposite direction, with the minimum on the vacuum side. Thin walls can be stiffened with rolled in ribs which are substantially thicker than the wall itself. This ribbed structure can be further strengthened by coaxial wraps over the ribs, or by longitudinal bars added outside the ribs. Methods of measuring and calibrating the hydrogen outgassing rates, and of presenting the data, will be discussed briefly.

10:40am **VT-FrM8 Increased Utilization of Semiconductor Process Equipment through Comprehensive Downstream By-product Management***, T.E. Nilsson,* Nor-Cal Products, Inc.

Fab maintenance personnel and equipment manufacturers share the common goal of extending preventative maintenance intervals and reducing wafer defects in process equipment in order to increase return on investment. Condensable by-product accumulation in forelines, dry pumps and exhaust lines is a significant contributor to wafer defects and planned and unplanned maintenance. Vacuum components, such as heater jackets and foreline traps, can extend preventative maintenance intervals dramatically when applied properly to a specific process. A Comprehensive Downstream Solution is one that first takes into account the specific process chemistries, temperatures and pressures, as well as any equipment constraints. The array of vacuum components and special treatments are passed through two filters: component configuration and a cost of ownership model. Component configuration considers the effect on the performance of the components by changing their relative position in the system. A cost of ownership model is developed with the customer for each option proposed showing the cost of the improvement and the pay back in terms of savings on maintenance and increased production.

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