Vacuum Technology Division
Room C120-122 - Session VT-TuA
Novel Vacuum Instrumentation

Moderators: Jason Carter, Argonne National Laboratory, **Yulin Li**, Cornell University

2:20pm **VT-TuA-1 Saving Energy of Subfab Equipment for Semiconductor Manufacturing**, ***Yohei Yoda,*** EBARA, Japan **INVITED**

Since the semiconductor industry has achieved continuous high growth in terms of both technology and commerce due to the spread of IACC5 * 1, the market will be doubled to 100 trillion yen in 2030 is a consensus in that industry. To purse miniaturization of devices based on Moore's Law, nanometer-order processing technology and three-dimensional processing technology are being researched and developed in various fields. Therefore, the increase in load and complexity of processes accompanied by the evolution of semiconductor manufacturing technology is remarkable. On the one hand, with an awareness of packaging technology, the diversification of processes and the increase in the number of processes will be further promoted in the future. On the other hand, as long as the increase in the production volume of semiconductor manufacturing and the number of processes, energy reduction and high efficiency during the manufacturing process are necessary issues in order to achieve a sustainable society in 2030.

In this report, we will discuss environmental technology development trends and roadmaps for 2030, whichregarding exhaust systems centered on dry vacuum pumps for manufacturing equipment that uses a large amount of energy in semiconductor manufacturing and exhaust gas treatment equipment which is responsible for reducing greenhouse gases.

Environmental Technology Development Trends for Exhaust Systems and 2030 Roadmap

The energy consumption ratio in semiconductor manufacturing can be roughly divided into consumption in equipment such as air conditioning, DI water and cooling water in clean rooms, and equipment in manufacturing equipment. Among these, the energy consumption ratio in the exhaust system including the dry vacuum pump in the manufacturing equipment is about half, which accounts for a huge proportion. Furthermore, to consume greenhouse gases such as CF4 and NF3 which produced during semiconductor manufacturing, exhaust gas treatment equipment is used to reduce the gases emission. The equipment used in the exhaust system uses utilities such as electric power, circulating cooling water, nitrogen, city water, fuel, and oxygen. Technological development for reducing usage and recycling / reuse will be an important performance index for 2030, along with achieving process performance and improving equipment availability. The latest technological trends regarding energy-saving technologies and on-demand control for each device will be reported and our environmental technology roadmap for 2030 will be explained.

3:00pm **VT-TuA-3 The Transfer of R&D Vacuum Products to Series Production - When Cleanliness and Quality Control Becomes Critical**, ***Klaus Bergner****, C. Worsch, F. Haidu, K. Marschall, M. Flaemmich,* VACOM Vakuum Komponenten & Messtechnik GmbH, Germany

Today's research in the field of vacuum technology is an essential enabler for lithography, measurement and correction of the smallest and most novel chip structures. This lays a foundation for future applications in medicine, communication or consumer electronics.

After a successful release, a market-driven transition from the R&D phase to volume production with short time-to-market cycles takes place. However, the ramp-up process can be challenging and could lead to several production errors or even destruction of substrates or modules. Troubleshooting is then often costly as personally supported prototypes leave the R&D status and obvious but uncommunicated details are overlooked. This is particularly crucial for ultra-clean vacuum systems, which require careful attention to design, production, cleaning, assembly and maintenance to prevent failure due to contamination.

Quality and process control of individual components and modules becomes critical to ensure the performance and reliability of the final system. In this talk, we will explore the challenges associated with ramping up individual components of ultra-clean vacuum systems and the measures that can be taken to reduce ramp-up time while maintaining quality.

We show how surface contamination can be reduced from a double-digit $\mu g/cm^2$ value to a single-digit ng/cm^2 value. We highlight the most essential steps in the design phase, the right choice of cleaning technologies, appropriate analyze methods and constant process monitoring.

In summary, we provide a decided insight into process chain for the realization of ultra-clean vacuum components in all stages of "cleanliness". True to the motto: Design clean, Plan clean, Make clean, Prove clean, Keep clean.

3:20pm **VT-TuA-4 High Temperature Inlet of Residual Gas Analyzers for Atomic Layer Deposition Process Monitoring**, ***Chenglong Yang,*** MKS Instruments, Inc. Mass Spectrometry Solutions Group*; J. Leslie, G. Jennings,* MKS Instruments, Inc. Mass Spectrometry Solutions Group, UK*; U. Meissner,* MKS Instruments, Inc. Mass Spectrometry Solutions Group, Germany*; M. Aitken, A. Wallace,* MKS Instruments, Inc. Mass Spectrometry Solutions Group, UK*; G. Brucker,* MKS Instruments, Inc. Mass Spectrometry Solutions Group

Residual gas analyzers (RGA) are used widely in the semiconductor industry for in-situ leak detection. Although RGAs can monitor contaminants, precursors and process byproducts in Atomic layer deposition (ALD), they are just used for process optimization/troubleshooting and are not yet ready for in-situ process monitoring owing to their short lifetime and less persuasive value for process monitoring. As an example, RGAs for ALD are challenged by harsh physico-chemical conditions including (1) chemical compatibility, (2) sensor contamination, (3) sensitivity degradation and (4) high measurement speed requirements. Many ALD precursors are liquid or solid at room temperature and can condense on cold surfaces, leading to blockage of the gas inlet system if the sampling pipes and valves are not at the required temperature conditions. MKS recently redesigned the popular UniBloc™ inlet system featured in most of its Process Analyzers to address the specific requirements of ALD. In its latest design, inlet components are uniformly heated (up to 200 ^{o}C) in order to avoid undesired reactions and/or deposition of byproducts prior to mass analysis. High sample flow rates, via bypass pumping, reduce sample transfer lag and improve sampling speeds as required for short pulse monitoring. Field replaceable valve seats and sampling orifices improve the lifetime and serviceability of the inlet system. Built-in calibration bottles, localized pressure measurement (Baratron® capacitance manometer) and sniffer tubes complete the new design and provide the performance and compatibility demanded by modern ALD processes. The improved Unibloc™ RGA design offers the opportunity to monitor ALD process in-situ, increase throughput and yield valuable process insights that will unlock future efficiencies in thin film growth.

4:20pm **VT-TuA-7 Improved Reliability of High Sensitivity Leak Testing of Large Chambers**, ***Brad Shaw,*** Leak Testing Specialists, Inc. **INVITED**

This paper will present practices that have been of great value in successful leak testing operations for very large high vacuum, and ultrahigh vacuum projects. *Successful* in this context refers to the delivery of technically reliable leak testing with consistent schedule durations at an efficient cost.

This list of practices is the accumulation of lessons learned through the leak testing of a number of large projects, including the leak testing of the Laser Interferometer Gravitational Observatory (LIGO) beam tubes, the development and implementation of the leak testing of the National Ignition Facility (NIF) beam path clusters, space simulation chamber shroud replacement, and a series of large, double wall, vacuum insulated spheres for liquid hydrogen.

Some practices described in this paper have been of sufficient value across an array of applications that they have been added to industry codes and standards for leak testing. Use of vacuum pumping the calibrated leaks for system calibration is an example of a practice developed on a large project, that is now included in ASTM Standard Practice E1603/1603M. Another example is the calculation of the Test Quality Factor (TQF) in each leak test and evaluating the test reliability against a double bound requirement. This refined TQF practice has been added to the revised ASME Mandatory Appendices for helium hood and helium filled object leak testing.

Some practices in this paper are “best practices” that are frequently neglected, but that have historically been of great value. One example is the neglect of leak testing new components at receiving inspection. Failing to perform leak testing upon receipt is a common source of project schedule and cost over-run. The successful builders of large high and ultrahigh vacuum systems are among the most consistent in leak testing components at Receiving, without regard to the source of the component or assurances that the product was leak tested by the manufacturer.

Many practices discussed in this paper offer innovative ways of doing common, but difficult leak testing tasks by simpler, faster, more consistent and reliable means. The use of helium receivers for rapid filling of large hoods is one example. There are also details for helium hood leak testing that are not commonly used but that can be a significant source of savings. Another example involves the use of the Test Quality Factor (TQF) as a sensor for predictive maintenance of leak testing systems.

For each of the practices discussed, we will present cases that illustrate the benefits derived from implementation, or cases of non-implementation and the resulting consequences.

We hope the paper will contribute to future successful leak testing of large, high-vacuum and ultra-high vacuum systems.

5:00pm **VT-TuA-9 An Alternative to Helium Leak Checking**, ***Kieran Massey**, J. Brindley, V. Bellido-Gonzalez, D. Monaghan,* Gencoa Limited, UK

The vacuum leak detection market is dominated by helium detection using quadruple-based mass spectroscopy. These detectors offer high sensitivity and have become the industry standard. Helium, which enables these leak checkers to function so effectively, has an uncertain future with a critically short supply and prices on the rise. Leak checkers based on this technology are also costly to buy and have high ongoing maintenance costs.

What is required is a detector that functions with a cheap, readily available and safe gas but can still offer detection levels relevant for the particular industry. An alternative gas sensor built around plasma emission monitoring enables detection of gases using a small remote plasma which can be converted into a helium equivalent leak rate. This sensor is based on RPEM technology (remote plasma emission monitoring) which offers greater robustness and reduced maintenance relative to traditional mass spectrometer-based gas detection.

The presentation will cover the technology of RPEM and how it has been adapted for leak checking of vacuum systems and components using argon and carbon dioxide gas as opposed to Helium.

5:20pm **VT-TuA-10 Reference Leaks for Traceable Outgassing Rate Measurements of Hydrocarbons and Water**, ***Annas Bin Ali**, M. Bernien,* Physikalisch-Technische Bundesanstalt (PTB), Germany; *J. Setina,* Institute of Metal Technology (IMT), Ljubljana, Slovenia; *K. Jousten,* Physikalisch-Technische Bundesanstalt (PTB), Germany

Outgassing from components built into vacuum process chambers remains a pertinent issue for the semiconductor industry and has gained much attention as in Extreme Ultra-Violet Lithography (EUVL) where vacuum cleanliness is requisite. Too high outgassing can cause reflectivity loss in optical tools due to reactions of the light with adsorbed molecules stemming from outgassing of both photoresist and internal surfaces. Water and hydrocarbons are the major outgassing species affecting EUVL reflectivity as they trigger the diffusion and carbon growth on the optical surfaces resulting in lifetime issues of the optics. Quadrupole mass spectrometers are widely employed to identify such outgassing species and quantify outgassing rates. However, quantitative gas rate measurements using quadrupole mass spectrometers lack the necessary metrological quality, and the measured quantity is not traceable. This could result in either underestimation or overestimation of outgassing rates. In this work, samples are developed and characterized to serve as reference and transfer standard for water and dodecane outgassing rates. Dodecane serves as a model contaminant for hydrocarbon outgassing. Reference samples are realized by using a silicone rubber as a permeate sandwiched between two CF16-sized stainless-steel discs having a hole on both sides which define the open area. The outgassing flow can be tuned by choosing the permeate thickness and the open area of the holes. The partial pressure calibration system of PTB was used to characterize the reference samples. The gas flow from a reference sample was compared with a gas flow of dodecane/water generated by means of a calibrated capillary. In this way the outgassing rate can be measured traceable to the international systems of units. The reference samples demonstrated stable permeation rates of dodecane/water with a relative standard deviation of ~ 3 % over the period of a year. The design of the reference sample offers the possibility to refill the reservoir without completely disassembling the permeation part.

5:40pm **VT-TuA-11 Anti-Deposition Sensor Diaphragm Structures of Sapphire-Based Capacitance Manometer for Semiconductor Manufacturing Processes**, ***Takuya Ishihara**, Y. Mastugi, M. Soeda,* Azbil Corporation, Japan

Recently, various new manufacturing processes are put into practical use in the semiconductor industry. Especially, Atomic layer processes such as Atomic Layer Deposition (ALD) and Atomic Layer Etching (ALE) are essential in the fine pattern processing. These processes are mainly used in high aspect ratio holes, narrow trenches, or complex 3D structures with micro to nano meter scale orders because of the excellent uniformity or step coverage based on the surface chemical reactions. On the other hand, because the film deposition could occur in any surface inside the process chamber, capacitance manometers used for pressure monitoring receive bad influences from these process with undesirable film depositions on the sensor diaphragm. These depositions often cause sensor output drifts which can lead to the process halt and need zero-point adjustments or the replacement of manometers. In the viewpoint of the productivity, this is crucial for any device manufactures. Similar problems are sometimes occurred in some kinds of conventional CVD (chemical vapor deposition) processes.

Authors have developed entirely sapphire-based capacitive pressure sensor chips (Fig.1) utilizing MEMS (Micro-Electro-Mechanical Systems) processes, which are packaged in capacitance manometers for semiconductor manufacturing (Fig.2). In fact, most of troubles we have in these applications are above mentioned depositions on the sensor diaphragm. In this paper we will present some improvement on sensor structure to resolve these issues, in which sensor output drift could be depressed even if deposition on the sensor diaphragm is occurred.

We take two of measures to correspond to properties of deposited films.

Structure1: For soft or fragile films which is often deposited during conventional CVD process.

These films tend to deposit mainly on open surface and not so much on the side wall or bottom of narrow trench structures. We used this property to divide films, which can weaken mechanical influence on the sensor diaphragm. Fig.3 shows the actual trench structure we fabricated on the sensor diaphragm surface.

Structure2: For hard or unformal films deposited in atomic layer processes.

These films deposited on any surface on diaphragms, so above-mentioned trench structure cannot be effective. Therefore, we improved sensor diaphragm edge structures to suppress diaphragm deformations accompanied with unformal film depositions based on mechanical simulation (Fig.4).

Finally, we have confirmed the effectiveness of these improvements in actual process. Fig.5 and Fig.6 are sensor output signals of improved sensors during the CVD process and the ALD process respectively compared with which of conventional sensors. These exhibit excellent anti-depo property of the improved manometers.

6:00pm **VT-TuA-12 Overview of the Vacuum Pumping Systems for the SPARC Tokamak**, ***Matt Fillion**, A. Kuang,* Commonwealth Fusion Systems; *C. Day,* Karlsruhe Institute of Technology (KIT), Germany; *O. Mulvany, F. Ravelli,* Commonwealth Fusion Systems

Commonwealth Fusion Systems (CFS) is a spin-off of the Massachusetts Institute of Technology aiming to bring fusion energy to the grid. To accomplish this, CFS is developing and commercializing the ARC fusion power plant. To achieve this, CFS is currently building the SPARC tokamak—a superconducting, high-field, deuterium-tritium fueled tokamak that is designed for Q>1.

The Vacuum Pumping System of SPARC consists of three primary subsystems. The cryostat pumping system generates and maintains vacuum insulation of the cryostat to support the superconducting magnets. The leak detection system provides vacuum guarding for the tritium secondary interspaces and double seals in SPARC. Lastly, the torus pumping system is responsible for four main functions: the containment of tritium, reaching and maintaining the primary vacuum vessel base pressure, the recovery of the inter-pulse pressure, and providing particle control during the plasma discharge by pumping from the divertor. Each of the three vacuum pumping subsystems has an independent set of two dry screw pumps to provide rough vacuum and fore line pumping, mag-lev turbomolecular pumps for achieving ultrahigh vacuum, and a residual gas analyzer for leak detection and analysis of the plasma exhaust composition. The cryostat and torus pumping systems each contain custom tritium compatible closed loop refrigerator cooled cryogenic pumps to provide temporary enhanced pumping speeds.

Divertor pumping is a key aspect of tokamak particle transport control and an important area of study for ARC and other fusion power plants. The divertor is where neutral pressures are the highest ensuring the most efficient pumping for helium removal (a fusion byproduct). However, high divertor neutral pressure is crucial for divertor heat exhaust mitigation. To provide better control, CFS is developing a variable conductance louver system for active control over the divertor pumping speed. SPARC would provide much-needed data on desired neutral pressures and particles throughputs for steady state operations on next step devices.

The high throughputs required—along with the need to pump tritium—means a commercial solution for divertor pumping is unavailable. Thus, CFS is working with a commercial partner to develop an all-metal sealed cryogenic pump to meet the divertor pumping requirements. Utilizing added thermal mass on the lowest temperature stage, together with a proprietary charcoal, this pump can provide pumping at throughputs of 10.6 Pa m^3/s for the 10 second flattop duration of a SPARC pulse.

This talk will provide a general overview of the SPARC vacuum pumping systems and associated challenges, with a focus on the torus pumping system and the design of a custom cryogenic pump required by this system.

Author Index

Bold page numbers indicate presenter