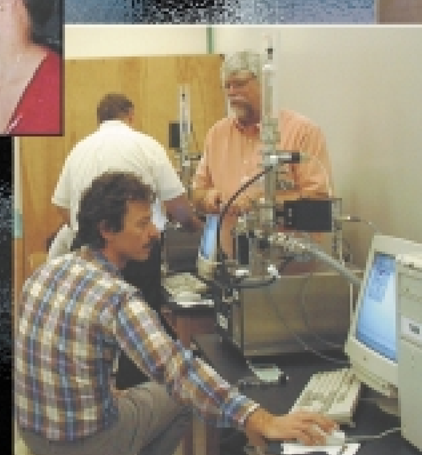
Vacuum Training for Manufacturing: Why and How



By Steve Hansen, MKS Instruments, Inc.

Many industries use advanced material processing methods to develop and manufacture products ranging from semiconductor devices to decorative coatings. These processes involve building up and often patterning thin layers of materials through the interaction of gases and solids in precisely controlled environments. A semiconductor process tool embodies a wide variety of features that are intertwined with vacuum theory and practice. Training is critical for an efficient, quality manufacturing operation. Training enhances skills and reduces the time wasted in troubleshooting and trial-and-error maintenance [1]. A knowledge of how vacuum tools and instruments work and how they produce and interact with the process environment plays an important role in reducing downtime and improving process uniformity. A skilled, well-informed workforce is important for efficient equipment utilization and continuous improvement.

Who Does the Training?

Short Courses

Traditional four-year programs leading to an undergraduate engineering or science degree focus on basic math, science, and engineering and rarely include time for much in the way of current manufacturing technology. This is left to on-the-job training by the employer and can be aided by attending process-specific short courses. An advantage of short courses is that they are continuously revised to keep up with the changing technology. The disadvantage is that they rarely include hands-on training.

Technology short courses can range from a half-day to four days in length. Both the basics and more specific topics – for example, reactive sputter deposition – are offered as short courses by colleges and professional societies. Introductory vacuum basics courses are sometimes included in the course programs at local colleges and universities. Off-site courses are usually held in local hotels, sometimes in conjunction with technical society meetings. On-site courses can usually be arranged. One popular course in basic vacuum technology is offered several times a year by the American Vacuum Society. The Society of Vacuum Coaters also offers a variety of vacuum- and process-related short courses.

Equipment-Specific Training

For those already employed in industry, process tool and component vendors often can provide on-site or off-site training that offers an understanding of instrumentation basics, such as pressure and flow control devices, vacuum gauging, and mass spectrometer residual gas analyzers or process monitors. Some component vendors also provide in-depth courses covering vacuum technology basics.

Most process tool vendors offer tool-specific, hands-on training, focusing on routine preventative maintenance procedures and troubleshooting. These courses provide hands-on training by the vendors who sell the process equipment. They focus on preventative maintenance and troubleshooting of recently purchased equipment. The cost may or may not be included in the equipment purchase price. This is part of on-the-job training that is paid for by an employer.

Steve Hansen joined MKS in 1995 to develop and deploy customer education programs and manage the Field Support Group, Vacuum Training System Program, and Customer Technical Training. In 2000, he was named Product Marketing Manager for pressure and gas flow calibration products. Under his leadership, MKS introduced the now industry-standard MKS Vacuum Training System for vacuum technology and instrumentation. Hansen has 24 years of experience in process development in semiconductor-related areas and holds two patents. Prior to MKS, he was with Digital Equipment Corp. He has a BSEE degree from Northeastern University.

Community College Technology Training Programs

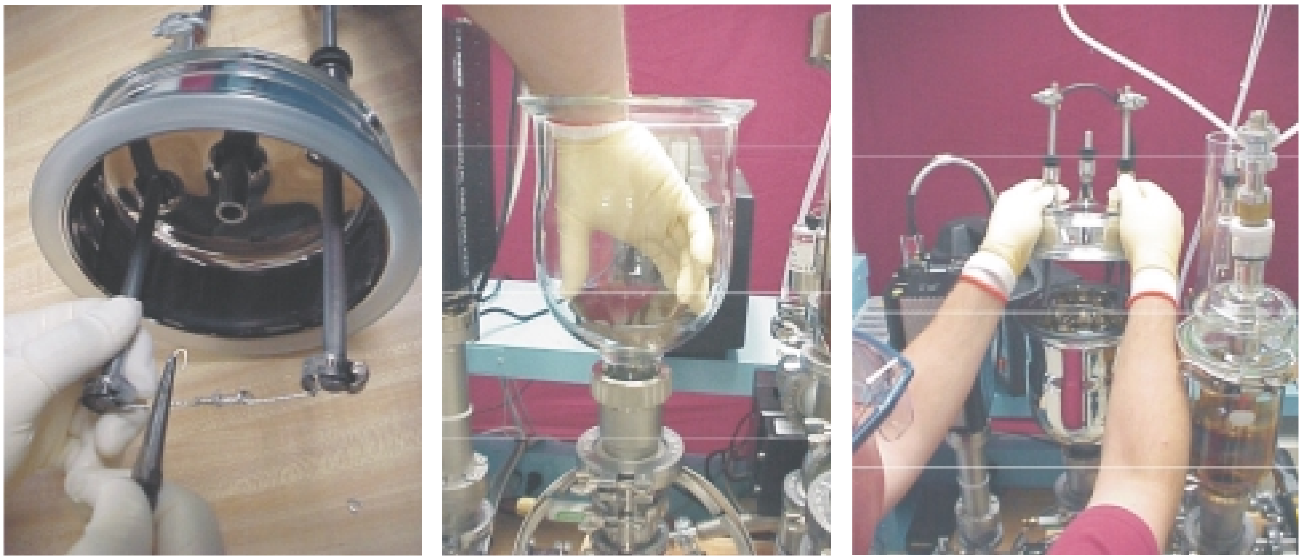
Industry would like to reduce the time required for on-the-job training of technicians and senior-level operators. To this end, employers would like to have a pool of knowledgeable job applicants. To meet this need, many community colleges are instituting two-year manufacturing technology programs that focus on the needs of local high-tech industries [2,3]. These programs often include courses on vacuum technology and radiofrequency (rf) plasma technology–environments that are common to many thin film and semiconductor deposition processes. Graduates with a two-year technical degree are well prepared for entry into, and further training in, the world of high-tech.

An example of this type of training program is one at Weatherford College in Weatherford, Texas. Weatherford, a small (2,000-student) community college about 30 miles west of Dallas-Ft. Worth, offers a two-year program leading to an Associate of Applied Science degree with a major in Engineering Technology. The program is in its third year and has had 45 graduates. Students receive quality training that leads to employment as an electronic, mechanical, or process technician.

Patrick McDonough, formerly lead instructor in Advanced Manufacturing Technology at Weatherford,* was in charge of a laboratory that provides students with hands-on training in vacuum maintenance, repair, and basic equipment calibration and troubleshooting. The course, entitled Vacuum Principles and rf Plasma Systems, is usually taken in the first semester of the second year. The class is limited to 15 students with 8 to 10 in the laboratory session. Experimental work is done using a commercial vacuum training system (see Sidebar) that has been enhanced by creative low-cost add-ons adapted from parts available at local home-improvement centers (**Figure 1**). For example, a $40 arc welder unit serves as a power supply for evaporation. An advantage of the system is that it can operate on a standard 120VAC, 20A circuit. Students start by assembling a demonstration system from separate components (**Figure 2**).

The laboratory is fortunate to also have a Lam Research AutoEtch 490 automated plasma etch system, which was donated by the manufacturer. This is used for laboratory exercises in

**A commercial high-vacuum training system with residual gas analysis capability.*



1a. Aluminum evaporation source 1b. Placement of substrate 1c. Closing deposition chamber

Figure 1. Modular system for vacuum evaporation experiments. Courtesy of Patrick McDonough, Weatherford Community College.

which the students create and enter recipes that use a plasma process for photoresist removal using benign gases (air, argon, nitrogen, oxygen). In this manner they can observe the effects of process parameters such as electrode gap setting, gas flow, and pressure measurement and control using an actual industrial process tool. A portion of a student exercise for an experiment is shown in **Figure 3**.

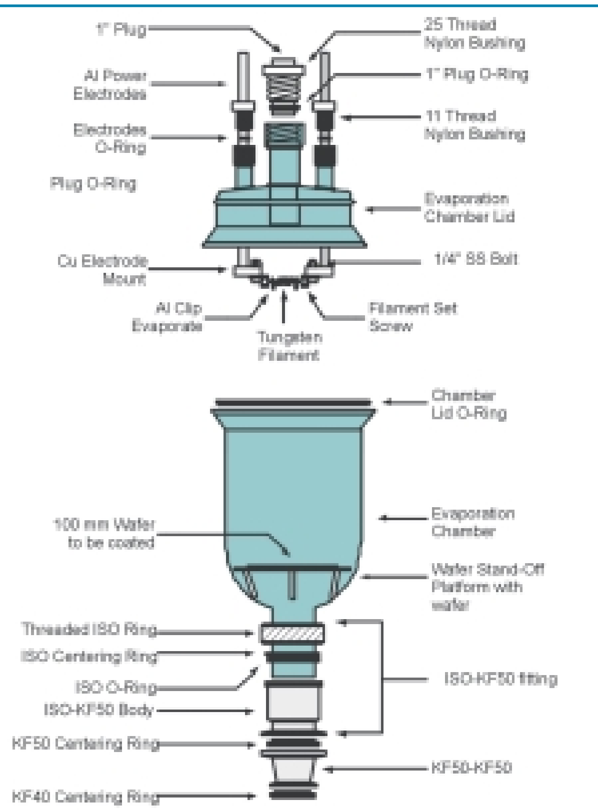


Figure 2. Components of evaporation module. Courtesy of Patrick McDonough, Weatherford Community College.

Example Start-Up Specification

1. Make sure that the vacuum system has been vented to atmosphere. If entire system is not at atmosphere see spec ######
2. Set the following valves, switch, and pumps at the following startup settings:
   a) Ion Gauge (10): Off
   b) Hi-Vac Isolation Valve (14): Closed
   c) Foreline Valve (15): Open
   d) Rough Valve (12): Closed
   e) Soft Pump Valve (2): Closed
   f) Vent Valve (9): Soft Pump Position
   g) Purge Valve (3): Soft Pump Position
   h) Throttle Valve (11): Open

The valve status is indicated by two LEDs located on the back of the Valve.

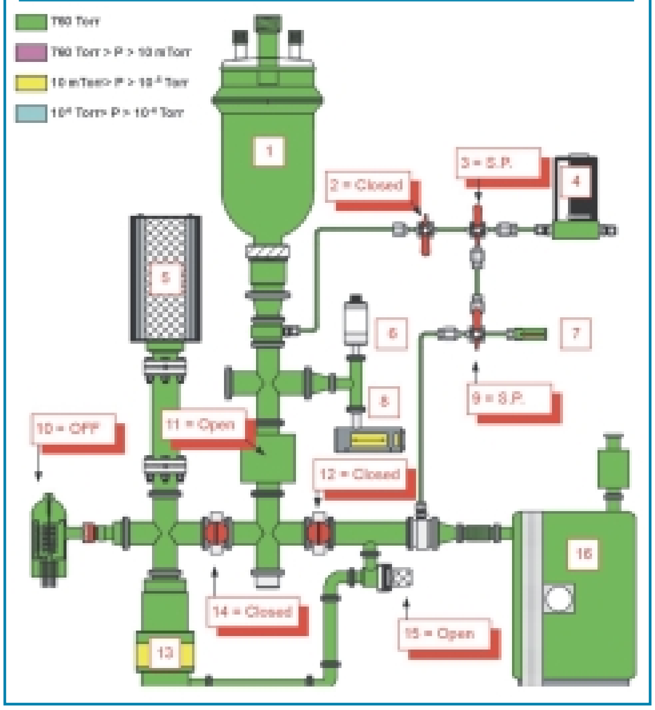


Figure 3. Portion of a Student Guide for start-up of a vacuum training system. Courtesy of Patrick McDonough, Weatherford Community College.

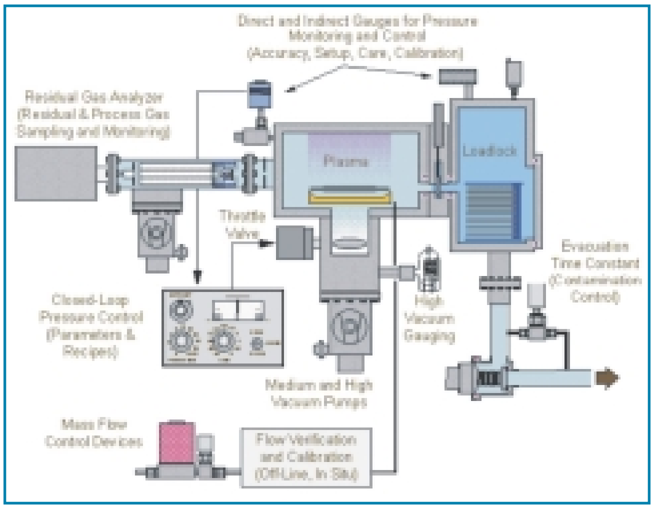


Figure 4. Simplified schematic diagram of a generic semiconductor process tool (plasma source not shown).

Figure 5. Automated system for sputter deposition of copper. Courtesy of Patrick McDonough, Weatherford Community College.

Process tools that are used in the semiconductor and vacuum coating industry are highly automated. Specialized process components such as mass flow controllers (MFCs) and throttle valves manage the flow rates of entering and exiting process gases, thus controlling the mixture and pressure within a process chamber. Other components measure total pressure and analyze and monitor the composition of process gases and isolate them from the environment outside of the chamber. **Figure 4** shows some of the vacuum control components of a generic process tool. The laboratory set-up that is used at Weatherford Community College to demonstrate how these components work together is shown in **Figure 5**.

Community Colleges across the U.S. are working together to develop manufacturing technology programs to meet the needs of local high-tech manufacturers. A “train the instructor” workshop for college teachers was held recently at Hillsborough Community College (HCC) in Tampa, Florida (**Figure 6**). HCC will offer their first manufacturing technology program this fall at their Brandon campus. In setting up vacuum-related training modules, Dr. Marilyn Barger, Associate Professor, Advanced Manufacturing Technology at HCC, has been building on the experience of Patrick McDonough in Texas. According to Dr. Barger:

“Although the term, ‘high tech’ usually generates images of computers and microchips, it also describes a complete sector of industries together with their supporting companies that are dedicated to the production of consumer goods and the complex equipment needed to advance our standard of living. The greater Tampa Bay region of Florida has dozens of high-tech companies that need employees with advanced technology training. These companies make everything from millions of tiny light-emitting diodes to specialized lenses for vision correction. Glass containers, sunglasses, smart wheel chairs, dialysis equipment, contact lens, special drill bit coatings, and airport security systems are all made in the Tampa Bay area using high-tech manufacturing processes.”

Hillsborough Community College’s manufacturing technology program is designed to give students the specific combination of science and technology skills needed to have an interesting and financially rewarding career in any of the Tampa Bay area high-tech companies. The HCC program leads to an A.A. degree in Manufacturing Technology. Developed under an NSF grant, it will include two vacuum-related courses: Vacuum

Figure 6. Train-the-trainer workshop and Hillsboro Community College. Courtesy of Marilyn Barger.

Science and Vacuum Technology (elective). A course on Advanced Manufacturing Processes, also elective, will have vacuum laboratory examples and activities. The program prepares students for careers as process or equipment technicians and operators. Dr. Barger explained, "Corporations are asking for a more skilled workforce and would like operators and technicians to know more about what is actually going on behind the tool interface and control panel." The program is not specific for semiconductor manufacturing but applies to all high-tech manufacturing tool and processes that use vacuum, hydraulic, and pneumatic systems.

Community College Training in Singapore

Chip manufacturers are rapidly expanding their fabrication operations in Singapore. Systems Silicon Manufacturing Corp. (SSMC), a joint venture with Philips Semiconductors, Taiwan's TSMC and Singapore's Economic Development Board (EDB) are investing U.S. $1.1 billion in new wafer fabrications. According to Philips, one of the reasons that Philips chose Singapore for the plant was because of government support in training employees. Other expansions underway include those of Chartered Semiconductor and ST Microelectronics. These expansions are driving the demand for personnel with technical training.

MKS-Singapore is actively supporting technical training at Singapore's technical schools and universities. MKS has supplied 15 MKS vacuum training systems to five colleges for use in semiconductor process courses. Schools using these training systems include: Nanyang Technological University, Temasek Polytechnic Engineering School, the Institute of Technical Training (ITE Yishun), Ngee Ann Polytechnic University, and Nanyang Polytechnic University. The technical courses offered by these schools and universities range from short courses in wafer fabrication to an M.S. degree in Microelectronics. All have web sites and course programs on line.

Summary

Vacuum technology training is essential for efficient high-tech manufacturing. Undergraduate and graduate schools provide the basics for engineering personnel. Ongoing up-to-date technology training can be gained by short courses given by pro-

Vacuum Training Hardware

Realizing that an understanding of vacuum and related process monitoring and control instrumentation is a key area for individuals who are preparing to become technical workers in the semiconductor industry, MKS has developed an integrated set of instructional hardware and literature for the teaching of vacuum and instrumentation practice. The centerpiece is a Vacuum Training System (VTS), a modular tabletop vacuum system that replicates the key features and functions of a full-scale process tool (**Sidebar Figure**).

The VTS incorporates the overall architecture and a variety of the features of a process tool into a student-friendly table-top classroom apparatus. Operating recipes can be set up and run on a desk- or lap-top computer. The software also has graphical displays that enhance the student's ability to understand the various facets of vacuum and vacuum systems. The system is extendible with add-on components that enhance the capabilities of the basic system. Other options can include digital instrumentation and rf-compatible chambers and fixturing.

A commercial high-vacuum training system with residual gas analysis capability.

It is designed as a representative medium vacuum process system with provisions for manual or automatic process control. Materials are provided for a one-day vacuum and process overview or a half-day training course that covers vacuum gauging including partial pressure or residual gas analyzers. The package provides corporations, colleges, and universities with the means to provide the fundamental vacuum and process training that is required by many manufacturing sites. Included are manuals with 30 experiments that illustrate the operation of vacuum-based process equipment, instructor presentation transparencies, instructor course guide, and materials for instructor training.

Training Module Course Content Descriptions of Exercises

The instructor's guide contains about 30 exercises. The following provides an outline of these exercises and how these relate to vacuum process tools.

Vacuum System Setup

The students are presented with a collection of individual components. They must assemble the components into a functional system. They learn:

* Identification and physical characteristics of various components, assembly of components using commonly used fittings, basic functions and relationships of the various components, electronic control systems, and entering parameters and menus on the computer.

- Instrument setup: scaling, zeroing, etc.
- Initial troubleshooting (base pres-

fessional societies, colleges and universities, and equipment vendors. Community colleges are innovating with manufacturing technology programs that fill the need of manufacturing organizations for process and equipment technicians who have knowledge of technology basics. Modular hardware for hands-on vacuum-based training is becoming available for use in community college programs.

References

1. S.P. Hansen, "Vacuum Instrument Calibration & Personnel Training Boost Productivity," *Vacuum Technology & Coating* 2(4), April 2001, pp. 46-50.
2. S.P. Hansen, "Hands-on vacuum training at the technical college level," *Solid State Technology*, November 1997, p.76-83.
3. Anon., "Capital: Intel Cost-Cutting Spares a College Tour," *The Wall Street Journal*, June 14, 2001, p.1.
4. Source: Maricopa Community Colleges (MATEC), Tempe, AZ - www.matec.org

Web Sites

- American Vacuum Society - www.avs.org
- Society of Vacuum Coaters -www.svc.org
- MKS Instruments Education page - www.mksinst.com/train.html
- Austin (Texas) Community College - www2.austin.cc.tx.us/Electron
- Hillsborough Community College, Tampa, FL - http://www.hcc.cc.fl.us
- Weatherford (Texas) Community College - www.wc.edu

Singapore Institutions and Programs:

- Temasek Polytechnic Engineering School, Diploma in Microelectronics - www.tp.ac.sg/courses/e08.htm
- Nanyang Technological University, M.S. in Microelectronics - www.ntu.edu.sg/registrar/postgraduate/coursework/mscme.htm
- Nanyang Polytechnic University, Electronics Program with Wafer Fabrication Option - www.nyp.edu.sg/seg/eg_ecco2.htm
- Ngee Ann Polytechnic University, Wafer fabrication (short course) - www.ced.np.edu.sg/courses.phtml? course_code=XC54
- ITE Yishun, Electronics (Wafer Fabrication) - www.ite.edu.sg/ntc2eswf.htm

sure capability and rate-of-rise leak test).

Vacuum Basics

These exercises delve into the basics of vacuum practice.

- Pumping system operation.
- Pumpdown time constant: what it is and how the time constant can be used as a diagnostic tool. Also, why control of the time constant is important to maintaining a low contamination environment.

This encompasses the use of low conductance bypass lines and explains the adverse effects of adiabatic cooling during pumpdown.

- Leaks: identifying real and virtual leaks.
- Locating leaks. Using simple techniques, leaks are intentionally introduced into the system and the students must locate and repair the leaks.

Once the concepts of mass flow are understood, students determine actual leak rates as expressed in terms of standard condition volumetric flow.

- Outgassing and permeation: effects of different materials, identifying these effects by observing the pressure versus time signatures.
- Throughput (Q) and its relationship to pumping speed or line conductance and pressure. This lays a foundation for understanding pressure control and mass flow control systems.

Gauging

A bewildering variety of gauges are used to monitor and control the system pressure. By comparing gauges, students will understand the differences between indirect (as exemplified by Pirani and ionization gauges) and the precision direct vacuum gauges (as exemplified by the capacitance manometer) that are used to control processes. Students learn about critical issues such as transient response, gas sensitivity, accuracy, and repeatability, etc.

Dynamic response characteristics. At various pressures and with differing pumpdown rates, a comparison is made between the behaviors of the convection Pirani gauge and the capacitance manometer. Students learn that the operating principles of a gauge have a direct influence on what the gauge is indicating and, under some circumstances, some gauges may be giving a totally wrong impression of what is actually taking place in the chamber.

Gauge calibration principles. A Pirani gauge is calibrated against a capacitance manometer of known accuracy using air and other gases.

Operation of an ion gauge. This exercise also demonstrates desorption effects and illustrates the bake-out process.

Closed-Loop Pressure Control

Many thin film and semiconductor processes live or die by the repeatability and stability of their closed-loop control systems. All tools have a variety of pressure and flow control systems. These exercises familiarize the students with pressure control systems in a variety of modes. The effects of various tuning parameters (proportional, integral, derivative) are seen in the way that the system responds while acquiring and maintaining specific set point pressures.

Manual pressure control. Students control the system using manual control valves. This explains the basic function of a closed-loop system and demonstrates the importance of the proper sizing of components in terms of control range.

Auto pressure control–downstream. This configuration is commonly found in chemical vapor deposition (CVD) and ashing tools. Students enter various set points and tuning parameters and observe pressure stability and throttle valve operation.

Auto pressure control–upstream. This configuration is commonly found in physical vapor deposition (PVD) tools.

Mass Flow Controllers

Mass flow controllers (MFCs) are the devices by which process and purge gases are delivered to the tool. Mass flow is usually measured in units of standard cubic centimeters per minute (sccm). The mass flow is actually an indication of how many molecules per minute of gas are being delivered to the chamber. MFCs represent another closed-loop control system where an input signal is translated into a specific mass flow of gas. A widely misunderstood component, a typical tool may use up to 100 MFCs. In this set of exercises, the students understand the operation and proper use of flow controllers, calibration and verification techniques, and basic troubleshooting.

MFC flow verification using pressure rate-of-rise. This is a two-part exercise that reproduces a typical in situ flow verification sequence. The students learn how the technique is performed, limitations on accuracy, and how the technique embodies the ideal gas law.

Developing a gas correction factor. MFCs are gas sensitive, and correction factors have to be determined for the various gases used in processes.

In situ MFC troubleshooting. This is a non-intrusive technique that can often diagnose problems even before they reach the state of catastrophic failure.

High Vacuum System Assembly and Operation

Students add a high vacuum (turbo-drag) pump to the system and learn the proper use of a high vacuum pumping system.

Use of a Residual Gas Analyzer (RGA)

Partial pressure measurement using the RGA serves as an important troubleshooting and diagnostic tool. RGAs may be used as part of maintenance routines, during process development, and for process monitoring and control. The RGA exercises introduce the student to the use of the instrument through a series of structured exercises that cover set up, various vacuum system configurations, and operational modes.

Using a sampling system with differential pumping. RGAs are high vacuum instruments, but the processes that they may monitor operate at much higher pressures. A sampling system is used to provide the required pressure drop from chamber to RGA.

- Performing a mass scan in analog mode
- Pressure versus time mode (often used for leak detection or process monitoring)
- The library function. The software tools that are used to identify the gases associated with the various peaks.
- Establishing a baseline to examine changes from the baseline condi tion
- Outgassing and permeation. Observing and identifying the gases that are released from various materials that may be found in a vacuum system.