

5 GENERAL OPERATING HINTS

5.1 HINTS ON HANDLING ELECTRON GUNS

5.1.1 HANDLING

Although the electron gun is quite rugged, it should be handled carefully and not knocked or dropped. Some guns have obviously-fragile ceramics and fine connections on the exterior of the gun tube; others have similar fragile parts inside the gun, which could also be damaged. Care should be taken that the gun does not hit against anything when inserting it or removing it from the vacuum chamber. Careful handling and storage are important when the gun is out of vacuum.

5.1.2 DUST AND DEBRIS

Precautions should be taken to keep dust and debris out of the electron gun and vacuum system. Some useful procedures are: wearing clean room gloves when handling the part of the gun that goes into vacuum, observing clean room procedures when working around UHV equipment, covering open vacuum ports when equipment is removed even temporarily, storing the gun properly.

Debris inside the electron gun can decrease performance and may cause discharging. Particles can sometimes be seen as irregularities in the spot viewed on a phosphor screen, while discharging may be observed as spikes in the emission current or pressure pulse in the vacuum chamber pressure.

Dust and debris can sometimes be blown off equipment using a can of compressed, microscopically-clean gas; this is not a substitute for keeping the gun clean. Bakeout (heating the gun to a high temperature, with any cables and heat-sensitive assemblies removed) can help to remove contaminants. The electron gun may be sent back to the factory for complete disassembly, cleaning, and rebuild of the firing unit assembly.

5.1.3 STORAGE

When the electron gun is not in vacuum, it should be stored carefully. Mounted guns can be bolted into their original stainless steel shipping tube to protect the knife edge on the flange and to keep the gun clean. Small unmounted guns and other parts can be placed in sealed bags, foil, or covered containers. The gun and other equipment which goes into vacuum should be stored on closed shelves.

Most guns can be stored in the laboratory at normal temperatures and pressures. While at room temperature, the standard refractory metal cathodes used in most electron guns are not harmed by repeated exposure to atmospheric gases. If a gun has a barium oxide (BaO) cathode, it is best to store the gun in vacuum; if it must be stored out of vacuum, it should be placed in a clean, dry environment such as a tightly sealed plastic box with desiccant, as BaO is susceptible to degradation by water vapor.

5.2 HINTS ON WORKING WITH VACUUM

5.2.1 HIGH VACUUM MATERIALS

All materials used in constructing the electron guns are compatible with ultra-high vacuum (UHV) technology. It is important that any materials used in vacuum with the gun be UHV-compatible or not out-gas, that is not release molecules when put into ultra-high vacuum.

The tiny gold-colored screws used in the gun are actually gold-plated stainless steel, which does not out-gas appreciably; if any screws are lost they should not be replaced with brass or other metal screws which could cause a problem with out-gassing. Gaskets used on the vacuum flanges should not be rubber, but either Viton or copper.

Feedthrough insulators are made of ceramic, which is extremely fragile and can be degraded by finger prints. Sometimes cutting a feedthrough wire or bending a pin can crack the ceramic insulator causing a leaky feedthrough.

In general, a number of common materials (such as most types of insulated wire, rubber tubing, electrical tape, tape labels, duct tape or anything with adhesive) are not vacuum compatible and must be avoided.

5.2.2 VACUUM TECHNIQUES

The quality of the vacuum affects the performance of the electron gun. The vacuum is usually achieved by the use of two pumps: a rough pump and a turbo-molecular pump. A trap between the pump and the vacuum system can help prevent oil from the pumps getting back into the system.

An ion gauge, which is actually an ion gun and detector system, is used to measure the gas molecules present in the vacuum chamber and so monitor the chamber pressure. The ion gauge should be attached to the vacuum chamber near the electron gun, but out of the way of the electron beam and target.

When starting the vacuum pumps, be sure to shut the vent valve; a hissing noise will be heard if the valve is not closed. While the system is pumping down, the pressure should be monitored by appropriate gauges (TC gauge, ion gauge, Penning gauge, etc.), as well as by listening to the sound of the pumps. It is a good idea to make an experimental pump down curve of the laboratory vacuum system, measuring the pressure in the vacuum chamber vs time; this graph can be useful for comparing the system's performance if there is a problem and for determining the time to establish a stable vacuum for the gun.

When bolting the electron gun or other equipment to a vacuum port, a new copper gasket should be used for a good permanent seal, because the knife edge on the flange cuts into the copper as the bolts are tightened. However, a Viton O-ring gasket can be used, and reused, for pieces that are frequently removed; with Viton, care should be taken that the gasket is clean, free of debris, properly-seated, and not pinched, or else it will leak. The bolts on the vacuum port should not be tightened all at once, but gradually in a (usually triangular) pattern such that bolts across from each other are tightened partially; the pattern is repeated until all the bolts are tight. This procedure should produce an even, tight seal.

If a hissing noise is heard (indicating a gross leak) when the chamber is evacuated, or if the turbo pump does not go up to full speed, or if the pressure does not seem to go down normally (for example, if it goes down but then goes up or varies), check the vacuum connections for possible leaks. Inspect Viton O-rings for pinches, debris, or slight irregularities, then replace or reposition them; tighten all the bolts on vacuum flanges with Viton or copper gaskets evenly.

Cleanliness is very important in maintaining a proper vacuum. In addition to dust or debris from the environment, the target itself can cause a problem. For example, phosphors from a phosphor screen target are sometimes found in the electron gun and on other surfaces in the vacuum chamber. The outside of the gun and other vacuum surfaces can be wiped off with Isopropyl alcohol and blown off with a can of microscopically-clean compressed air. For more complete cleaning, disassembled parts can be washed in distilled water and a concentrated cleaning solution (such as Micro-90, a mixture of water, glycine, benzenesulfonic acid and other agents) and cleaned by ultrasonic vibration.

Before turning on the electron gun, it is essential to establish a stable vacuum. After the gun is turned off, the cathode must be allowed to cool down before the vacuum system is vented. A poor vacuum can damage the cathode or reduce its lifetime.

If the electron gun is energized without a proper vacuum, it can be damaged by arc-overs and can expose the operator to a severe electric shock hazard.

(See also Hints on Setting up the System- Vacuum Requirements.)

5.3 HINTS ON SETTING UP THE SYSTEM

5.3.1 INSERTING THE GUN

When inserting the electron gun into the vacuum system, care must be taken to avoid damaging either the gun or the cables. Plastic gloves should be worn when handling the gun, so that the whole gun can be held and supported without contaminating the vacuum surfaces with fingerprints, (unless the gun is very small and can be easily held by just the part of the flange which is outside vacuum). Do not handle connector ends, gaskets, or other surfaces exposed to the vacuum with bare hands, because degradation of the insulator and vacuum surfaces will result if contaminants are present in the system.

Be sure that there is adequate clearance and working distance in the vacuum system before inserting the gun, and then be sure to insert the gun carefully straight through the port. If the gun is knocked against the vacuum system, the lens elements in the gun can become misaligned, and fragile insulators can easily be broken. If there is a Faraday cup on the end of the gun, additional clearance will be needed to allow room for the Faraday cup to swing into and out of line.

Before bolting the gun into vacuum or connecting the cables to the gun, it is a good idea to check the positioning of the gun and cables. Observing the location of the key on the gun connector and the key on the end of the cable will allow the gun and cable to be approximately lined up before they are connected. The cables may be damaged if they are twisted or bent, or if too much force is used when connecting them; excessive force could also damage the gun. In addition, the gun deflection plates should be oriented relative to the experimental target before tightening the bolts and connecting cables.

When bolting the gun on to the vacuum port, the bolts should be tightened gradually and evenly, in a pattern that alternates sides, so that there is a good seal and so that the gun is not pushed over to one side. If a mechanical alignment device, such as a Port Aligner, is used, care must be taken that it does not cause the gun to hit the vacuum system which can bend the gun body.

5.3.2 WORKING DISTANCE

In setting up the system, the working distance (the distance from the end of the electron gun to the target) will need to be determined. Many of the gun specifications are affected by the working distance; for example, at a longer working distance, there is more effect of noise, and beam current may be less, or the spot size may be larger. In general, the minimum working distance possible for the experiment should be chosen in order to reduce problems associated with transport of electrons including space charge spreading of the beam and beam distortions from stray magnetic fields and stray electric fields (i.e. the Earth's magnetic field and insulator charge-up).

5.3.3 BAKE OUT

To remove contaminants, adsorbed materials, water vapor etc. that may interfere with vacuum or with the electron gun performance, the gun as well as the vacuum chamber can be heated to the temperature given in the gun specifications. When heating the entire vacuum chamber, do not exceed the recommended maximum temperature for the laboratory turbo-pump flange.

After all cables and any heat-sensitive assemblies are removed from the gun, bakeout may be accomplished by a variety of methods, including electrical heating tapes, heating pads, an oven-like bakeout chamber, or UV light for some gases. For example, heating tapes can be wrapped flat around the vacuum chamber, a temperature probe laid against the metal, and the whole chamber wrapped in aluminum foil, being careful not to put tapes or foil over any glass windows. The heating tapes can be turned on and off to maintain the desired temperature for the desired time, usually several hours to 24 hours for the first bakeout depending on the size of the chamber.

In some guns, there are magnetic coils, a pneumatic Faraday cup actuator or other assemblies which are more heat-sensitive and must be removed or heated differentially. For example, on a gun with magnetic focus coils, heating tapes could be applied to only a part of the gun and the temperature could be monitored in the different areas. Care should be taken that these assemblies are not heated above their recommended maximum temperatures.

The time can be reduced for subsequent bakeout by back-filling with a dry gas, such as N_2 , when venting the chamber instead of letting in normal atmosphere. The removal of some materials, such as hydrogen, may take a long time.

The amount of water vapor or other materials present can be measured by a residual gas analyzer (RGA) to determine when bakeout is complete. Be careful to monitor the temperature of the gun and chamber with a probe during bakeout so that the temperature does not exceed the recommended value for either the gun or the pump.

5.3 HINTS ON SETTING UP THE SYSTEM cont.

5.3.4 THE ENVIRONMENT

(Vacuum Requirements, Chamber, Electric and Magnetic Fields)

Vacuum Requirements

Before turning on the electron gun, it is essential to establish a stable vacuum. An electron gun with a standard refractory metal cathode requires a vacuum of 10^{-5} torr or better, while a gun with a BaO (barium oxide) or a LaB₆ (lanthanum hexaboride) cathode requires 10^{-7} torr, but one with a ThO₂ (thorium oxide-coated iridium) cathode requires only 10^{-4} torr. It is important to consider that, depending on how the vacuum system is set up in the laboratory and the position of the ion gauge, the actual vacuum level in the region of the electron gun may not be as good as where the vacuum is being measured.

A poor vacuum can damage the cathode or reduce its lifetime. For example, the presence of oxygen or water vapor while the refractory metal cathode is hot (over 700 K) will cause oxidation of the metals, while at higher temperatures (over 1200 K) nitrogen will further degrade the cathode. Thus, the vacuum must be well established before the gun is turned on, and after the gun is turned off, the cathode must be allowed to cool down (usually for at least a half hour) before the vacuum system is vented.

If the electron gun is energized without a proper vacuum, it can be damaged by arc-overs and can expose the operator to a severe electric shock hazard.

Vacuum Chamber

When the electron gun is run, there is danger that the vacuum chamber and objects inside it may charge up causing discharging and a HIGH VOLTAGE HAZARD. The vacuum chamber must be connected to a proper Earth ground. In addition, any unused electrical feedthroughs on the vacuum system, such as BNCs, need to be grounded or they will charge up.

Space inside the chamber should be kept as clear as possible. Non-conductive materials inside the vacuum system, such as plastics, ceramics, or coated wires, can charge up and affect the electric field inside the chamber. For example, a stray coated wire near the beam could repeatedly charge up and discharge, causing the electric field to vary; this would distort the beam and make the spot appear to jump repeatedly.

Electric and Magnetic Fields

Tools, metal pens, metal rulers, magnets and similar objects should not be left in the working area around the electron gun. Such objects and nearby electrical equipment can cause distortion or deflection of the electron beam. Background 60-cycle noise can also affect performance. In some cases, a sheet of μ -metal (*mu-metal*) wrapped around the gun can be used to help shield the gun from stray electromagnetic fields.

5.3.5 SETTING UP THE POWER SUPPLY (Location, Cable Support)

In general, the Power Supply must be located close enough to where the electron gun will be installed in vacuum that the cables will reach easily and not be bent sharply, usually within 2 meters of the gun. There must also be adequate clearance in back of the Power Supply for access to the rear panel, usually at least 0.5 meters of clearance. Space is needed so that cables can be plugged in without being bent and so that the remote controls on the rear of the Power Supply can be reached. In addition, the power cord must be easily accessible, so that it can be removed from the AC main outlet for shutdown in case of an emergency.

It is important that the High Voltage cables from the power supply to the gun not be bent or twisted excessively. Multiple cables can be held together with plastic cable ties and fastened to a nearby rack or pipe at several spots to support the cables and prevent them from being twisted, bent at a sharp angle or stepped on in the lab.

5.4 HINTS ON OPERATING ELECTRON GUNS

5.4.1 HIGH VOLTAGE AND X-RAY SAFETY

Safety from possible hazards due to High Voltage or X-ray radiation must be a consideration in setting up and operating the entire system. Proper high voltage precautions and grounding techniques must be observed.

In no event should the Power Supply be energized unless the electron gun is bolted into a properly evacuated high vacuum chamber. Proper vacuums are better than 1×10^{-5} torr for refractory metal cathodes, or better than 1×10^{-7} torr for LaB₆ and BaO cathodes. To energize the system without proper vacuum would cause the gun to be damaged by arc-overs, that expose the operator to a severe electric shock hazard.

In no event should the safety interlocks on the High Voltage cable, or in the Power Supply, be disconnected or bypassed.

For a higher-powered electron gun (over 10 keV): Since high energy electrons striking targets or any other surface on the interior of the vacuum chamber may generate x-ray radiation, x-ray radiation shielding is recommended when using the electron gun. This x-ray shielding is part of the host vacuum system. Therefore, the purchaser must observe proper radiation shielding procedures to protect personnel and/or property when designing the host vacuum system into which the gun is to be inserted.

When observing the target area of a higher-powered electron gun (over 10 keV), it is necessary to cover standard glass viewports with leaded glass; failure to do so could increase the risk of exposure to x-rays. Unleaded viewports are transparent to x-rays, so direct viewing of the cathode or target area through normal glass viewports is a radiation health hazard.

The purchaser's safety officer should inspect the installation and shielding of the electron gun prior to operation.

5.4.2 APPLYING HV: DISCHARGING

Discharging (sparking) can occur during operation of the electron gun if there is contamination, or a potential that builds up on gun elements, or a short somewhere in the gun. Such discharging can usually be observed as a momentary jump of the emission current metering readout; occasionally it can be heard.

If the gun has been out of vacuum, it is not unusual for there to be a small amount of discharging when the gun is first brought to high voltage or when the source current is first turned up to warm up the cathode. These initial discharges are due to impurities picked up by the gun while out of vacuum; however, this condition should not persist.

Discharging which continues or recurs cyclically probably indicates a problem with the gun, power supply or cables, and the gun should be turned off. Of course, if the user experiences a shock from touching any part of the system, there is a problem, and the system should be shut off immediately and indirectly (without touching the system).

5.4.3 APPLYING SOURCE CURRENT: CATHODE LIFETIME CONSIDERATIONS

In general, the higher the source current which is applied, the hotter the cathode becomes, and the shorter its expected lifetime. The cathodes used in the electron guns are quite rugged. The two factors that affect the cathode most are the temperature at which it is heated and the quality of the vacuum. Typical lifetimes for refractory metal cathodes range from less than 500 hours to over a thousand hours, depending on the filament current used and the vacuum environment.

Useable lifetimes for the lanthanum hexaboride (LaB₆) cathode can be thousands of hours. The lifetime of a BaO-coated or ThO₂-coated cathode or of a LaB₆ crystal cathode is based on the evaporation rate of those materials, which is dependent on the temperature at which the cathode is run and the vacuum.

The work function of the cathode also affects its lifetime; contamination of the cathode surface can increase the work function, increasing the filament current needed to produce the same beam current, and so burning out the cathode more quickly.

Cathodes should not be run at more than the recommended emission current given in the operating instructions. A higher current and high cathode temperature will cause the cathode to fail rapidly. In general, when the gun has been out of vacuum, the source current should be increased gradually, allowing the cathode to warm up. There is a trade off between overall cathode lifetime and speed of warm up; for some applications the user may choose to increase the source current quickly, but this will decrease the lifetime. Most cathodes which remain in vacuum may be brought to the desired temperature more quickly without causing damage.

Throughout the cathode's lifetime, the achievable beam current should be stable once the cathode has warmed up. It is a sign that the cathode is failing, if the operating parameters change drastically and a much higher source current is required to achieve the previous normal level of emission. Electron guns can be rebuilt at Kimball Physics, including the installation of a new cathode; in many guns, the cathode (firing unit assembly) is also user-replaceable according to detailed instructions in Section 6.

5.4 HINTS ON OPERATING ELECTRON GUNS cont.

5.4.4 ADJUSTING AND OPTIMIZING PARAMETERS

For optimal performance of the electron gun, the various operating parameters should be carefully adjusted. Some typical values at which the gun was run during testing at Kimball Physics can be seen in the graphs in the Data Section. However, as the experimental set-up may vary, it is necessary to empirically adjust the parameters and evaluate the results by measuring beam current or spot size or whatever else is critical for the particular application.

When adjusting parameters with the FlexPanel controls, it can be useful to save an intermediate value with the STORE menu item before making further changes. Settings can also be saved when using the LabVIEW computer control program.

Adjusting one parameter often has an affect on the others, and so some fine-tuning is necessary. For example, changing the grid voltage affects the position of the crossover in the triode, so that the focus voltage will need re-adjusting to maintain a constant spot size. In addition, there is a change in emission over the warm up period, so parameters may need adjusting later from their initial settings. Not only the settings of the controls on the power supply, but other system variables such as pressure or working distance, have an effect on the results.

Some parameters are linearly dependent on another parameter. For example, the beam divergence depends on the electron acceleration energy among other factors, so in some electron guns, the focusing voltage needed to produce a particular spot size varies approximately linearly with the energy. In such a case, once the appropriate focus setting has been determined at one energy level, it can be useful to set the focus to be proportional to the energy with the FlexPanel control menu.

5.4.5 USING THE POWER SUPPLY CONTROLS

With the FlexPanel controller, the individual power supplies which apply voltage to various gun elements can be controlled either manually by the encoder wheel on the front of the Power Supply or indirectly by a signal into the remote connectors on the rear of the Power Supply.

The manual encoder wheel is a large gray rotary switch that adjusts the programming signal of the individual power supply that is currently selected on the display. Clockwise rotation increases the signal, and counterclockwise decreases it, but the signal is not directly proportional. The rate of increase/ decrease varies with the speed that the knob is rotated to allow for quick rough adjustment or slow fine adjustment. The encoder wheel is also used to adjust values for menu items, such as screen brightness.

The encoder wheel is designed to be turned easily and rapidly with a finger in the depression. When new, however, the wheel may be stiffer. The large outer edge allows slower, more precise movement. One slow click with the wheel will adjust the value by one unit in the last decimal place. Because the encoder wheel has a variable rate of increase/decrease, it is possible to turn a control higher than is intended. In addition, there may a delay in the response to supply voltage changes due to capacitance in the gun system and protection circuitry. Thus it is advisable to be careful in turning the wheel and wait to see the effects when increasing a critical supply such as source or energy.

The actual output range of a particular power supply may not be the same as the full potential range of the supply or the range given for the corresponding remote control/ metering signals. For example, the Source may be a 0 to 2.0 V supply, but the Source power supply may be set with a Zener limit of 1.5 V to prevent cathode damage, so that the actual range is 0 to 1.5 V. In this case, turning the encoder wheel as far as possible will yield 1.5 V, not 2.0 V. With the analog remote control, a 0 to 10 V input signal corresponds proportionally to 0 to 2.0 V, so a 5 V signal will produce 1.0 V, but with the limit, any input signal greater than 7.5 V will produce only 1.5 V of Source. The counts used in the RS-232 or RS-244/RS-485 programming will be similarly limited.

The local and remote controls for any individual power supply (e.g. energy, source, grid, focus, etc.) are mutually exclusive; that is, the supply can not be in manual (local) and remote control mode at the same time. However, metering is not affected by the remote/local mode. The front panel display will show the supply outputs whether or not they are also being monitored remotely. It is possible for one supply to be in remote mode while another is in local mode. For example, deflection could be controlled manually by an operator to position the beam on a particular target, while the energy and source were controlled by computer.

For each individual power supply, the local or remote mode is selected by one of a set of switches on the back of the Power Supply. If turning the encoder wheel on the front of the power supply does not produce a change in the selected supply, check that the corresponding switch in back is not in the remote position. Conversely, if an analog remote control signal does not appear to produce an effect, check that the switch is not in the local position. Note that the RS-232 or RS-244/RS-485 programming requires that the switches be in the local position because it communicates directly with the FlexPanel controller as the encoder wheel does.

5.4 HINTS ON OPERATING ELECTRON GUNS cont.

5.4.6 DETECTION TECHNIQUES (Faraday Cups, Phosphor Screens)

Faraday Cups

A Faraday cup connected to an ammeter can be used to detect and measure the actual beam current emitted from the electron gun. The Faraday cup consists of a hollow stainless steel cylinder closed at the base, with an appropriately sized aperture for collecting the electrons. An electrical connection is made to the Faraday cup to conduct the current to a vacuum electrical feedthrough and then to an ammeter. For best performance, an outer, grounded cylinder can be used for shielding.

The user can construct an appropriate Faraday cup (a full line of eV parts is available from Kimball Physics) or can order a Faraday cup and mounting system from Kimball Physics. The Faraday cup can be completely separate from the gun, or with some gun models, it can be part of an assembly mounted to the end of the electron gun and manipulated remotely with a manual knob or a pneumatic control.

To reduce scattering of electrons collected in the Faraday cup and to reduce secondary electron emission, the Faraday cup can be electrically biased. For electrons, +50 V, is typically adequate. This can be accomplished by placing a battery between the vacuum feedthrough and the ammeter.

A good way to assess beam uniformity is with a small Faraday cup on a device which can be made to scan across the beam. A closely packed set of three or four electrically-isolated Faraday cups on a manipulator would allow for simultaneous comparison of beam current density along several chords across the spot. Close to the end of the gun, spot size will be small and so a small Faraday cup translation will traverse a large percentage of the spot, while beam current density will be relatively high. Farther from the end of the gun, the spot size is larger, allowing for either more Faraday cups in the set or larger step sizes in the translation of a single Faraday cup. Beam current density will be correspondingly smaller. It may be useful to assess the beam current density distribution at a longer working distance where the spot is larger, then apply a transformation to these measurements to obtain beam current density across a spot at the desired working distance.

Phosphor Screens

During the initial operation of the electron gun system, the use of a grounded phosphor target screen is helpful as it allows visual, real-time observation of the spot. The phosphor screen emits light (photons) when bombarded by high energy particles (threshold value approximately 500 eV for electrons). The light color, typically blue or green, depends on the phosphor material. The screen can be used for alignment and to set the proper operating parameters necessary to obtain maximum beam uniformity.

Note that excessive power may cause phosphor screen damage. To preserve screen brightness, it is advisable to use the lowest power density that provides a clear spot. This density is calculated as the beam current times the beam energy divided by the spot size area. For standard Kimball Physics phosphor screens, the recommended maximum beam power density is 1 Watt/cm².

Phosphor screens of various sizes made with high luminosity P22 phosphor (ZnS:Ag) can be purchased from Kimball Physics.

5.5 GENERAL LABORATORY REFERENCES

The following books may be useful in working with electron or ion guns:

Bakish, R., ed. *Introduction to Electron Beam Technology*. John Wiley & Sons, New York, 1962.

Cherepin, N.V. *Treatment of Material for Use in High Vacuum Equipment*. Ordentlich, , 1976.

Cumo, J.J., S.M. Rossnagel, and H.R. Kaufman. *Handbook of Ion Beam Processing Technology-- Principles, Deposition, Film Modification and Synthesis*. Noyes Publications, Park Ridge, NJ, 1989.

Kohl, W.H. *Handbook of Materials and Techniques for Vacuum Devices*. Reinhold Publishing Co., New York, 1967.

Lafferty, J.M., ed. *Foundations of Vacuum Science and Technology*. John Wiley & Sons, New York, 1998.

Lide, D. R. ed. *CRC Handbook of Chemistry and Physics*. CRC Press, Boston, 1991.

Moss, H. *Narrow Angle Electron Guns and Cathode Ray Tubes*. Academic Press, New York, 1968.

O'Hanlon, J.F. *A User's Guide to Vacuum Technology*. John Wiley & Sons, New York, 1980.

Pierce, J.R. *Theory and Design of Electron Beams*. Van Nostrand Co., New York, 1954.

Redhead, P.A., J.P. Hobson, and E.V. Kornelson. *The Physical Basis of Ultrahigh Vacuum*. American Institute of Physics, New York, 1993.

Roth, A. *Vacuum Technology*. North Holland Physics Publishing, Amsterdam, 1986.

Sedlecek, M. *Electron Physics of Vacuum and Gaseous Devices*. John Wiley & Sons, New York, 1996.

Wilson, R.G and G.R. Brewer. *Ion Beams with Application to Ion Implantation*. John Wiley & Sons, New York, 1973.