BROOKS AUTOMATION

Introduction to Bayard-Alpert Ionization Gauges

Technical Note

Introduction

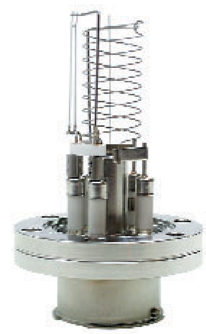
This technical note discusses the different types of Bayard-Alpert (B-A) gauges, basics of operation, components of a B-A gauge, and degassing techniques.

A Bayard-Alpert vacuum gauge ionizes the gas molecules within the gauge volume, collects those ions on a thin ion collector wire, and measures the resulting current to the ion collector to determine the number of molecules present and indicates a pressure based on that measurement.

The Bayard-Alpert gauge was invented by R.T. Bayard & D. Alpert in 1950 to overcome a limitation in vacuum pressure measurement by the triode gauge. The triode gauge cannot indicate pressure lower than 10^{-8} Torr because electrons striking the grid create low-energy x rays, which emit photoelectrons when they strike the ion collector. The current that results from the photoelectrons leaving the collector is what causes the lower pressure limit of the triode gauge. The solution proposed by Bayard and Alpert was to reconfigure the collector and grid of the triode gauge to lower the current from the x ray effect.

Stabil-Ion® Gauge

Glass B-A Gauge



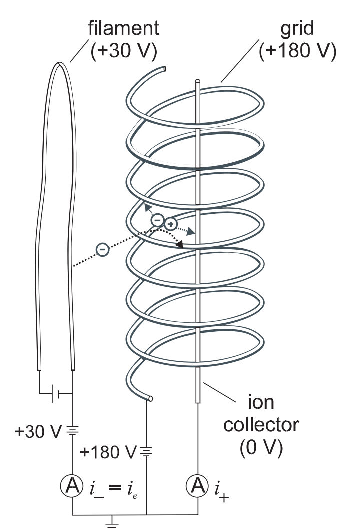
Nude B-A Gauge

UHV Nude B-A Gauge

Operating Principles of Bayard-Alpert Ionization Gauges

A Bayard-Alpert (B-A) gauge is a hot-filament style ionization gauge. It is called such because a heated filament (cathode) is used to emit electrons toward a grid (anode).

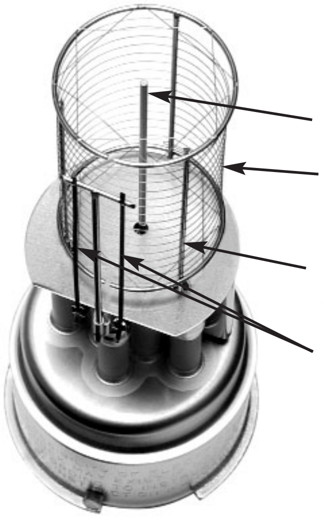
The pressure indication of a B-A vacuum gauge is based on the ionization of the gas molecules by a constant flow of electrons. The negative electrons are emitted at a well-controlled, selectable rate from a heated filament (cathode) and are accelerated toward a positively-charged wire grid (anode). Electrons pass into the space enclosed by the grid. In this space the electrons collide with the gas molecules that are in the vacuum system, and produce positive ions. The positive ions are then collected by the ion collector that is located along the axis of the cylindrical grid. The ion collector is at nearly ground potential, which is negative with respect to the grid. At a constant filament-to-grid voltage and electron emission current, the rate that positive ions are formed is directly proportional to the density of molecules (pressure) in the gauge for pressures below approximately 1 x 10^{-3} Torr. The strength of the ion current is then indicated on an electrometer that is calibrated in units of pressure.



Electrons are created by a hot filament and accelerated to the grid. The current is actively controlled by the electronics.

Because the pressure indication is linear, the hot cathode B-A gauge is generally considered to be the most accurate continuous indicator for pressures below 1 x 10^{-3} Torr.

The development of the Stabil-Ion Gauge® brought the accuracy of B-A technology to the 4% to 6% range. Although prior B-A style vacuum gauges were usually inaccurate as much as 20% to 50%, they were still the best, commonly available vacuum gauge in the 1 x 10^{-3} to 2 x 10^{-11} Torr range.



Stabil-Ion® Gauge from Granville-Phillips®
(Shown with the stainless steel enclosure removed for clarity.)

X Ray Limit of Bayard-Alpert Gauges

The low end of the operating range of a B-A gauge is determined by the x ray limit of this type of gauge. The x ray limit varies with different gauge designs. X rays are produced when the electrons emitted by the cathode impact the grid (anode). Because of the geometry of the B-A gauge, only a small fraction of the x rays emitted from the grid are intercepted by the ion collector. When the x rays strike the collector they cause electrons to be photoelectrically ejected from the collector. This photoelectron current from the ion collector is detected the same as positive ions arriving at the ion collector and consequently adds to the ion current. This x ray current limits the pressures that can be measured, and is equivalent to a pressure reading in the 10^{-10} to 10^{-11} Torr ranges. Earlier design triode gauges which have a cylindrical collector outside the grid experience an x ray limit of about 10^{-8} Torr. The x ray limit refers to the lowest pressure indication that may be obtained in a gauge when all the output current is due to x ray induced photoemission and there is an absence of gas.

The x ray limit of standard glass or nude B-A gauges is approximately 3x10^{-10} Torr. To measure below this limit, an ultrahigh vacuum (UHV) nude B-A gauge can be used. The UHV nude gauge has an x ray limit of approximately 2x10^{-11} Torr. This lower x ray limit is achieved by modifying two elements of the standard B-A gauge design. First, the diameter of the collector is reduced. The smaller cross-sectional area reduces the probability that the x rays created at the grid will strike the collector. Second, the helical grid structure is replaced with a fine-wire mesh grid structure, and there is also a fine-wire structure across both ends of the grid. The fine grid wires provide a more transparent grid for longer electron path lengths, and the grid ends confine the positive ions for better ion collection. Together, these two modifications cause a higher gauge sensitivity for ions from the gas phase which causes the x ray current to be converted into a smaller pressure indication (i.e., a lower x ray limit).

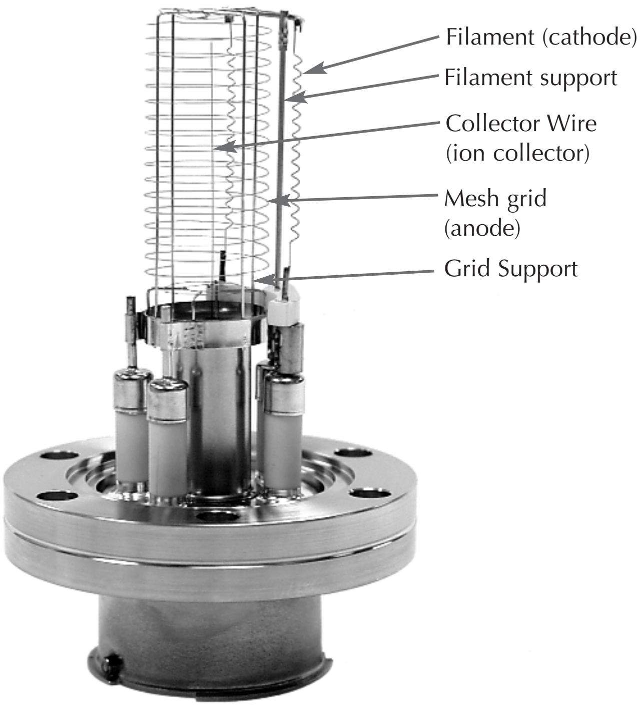
Some processes can result in deposits on the electrodes. These deposits can lead to an increase in x ray limit since more electrons are released under x ray bombardment. Process deposits can generally be removed by degassing the electrodes. See *Degassing* on the next page.

Filaments (Cathodes) used in Bayard-Alpert Gauges

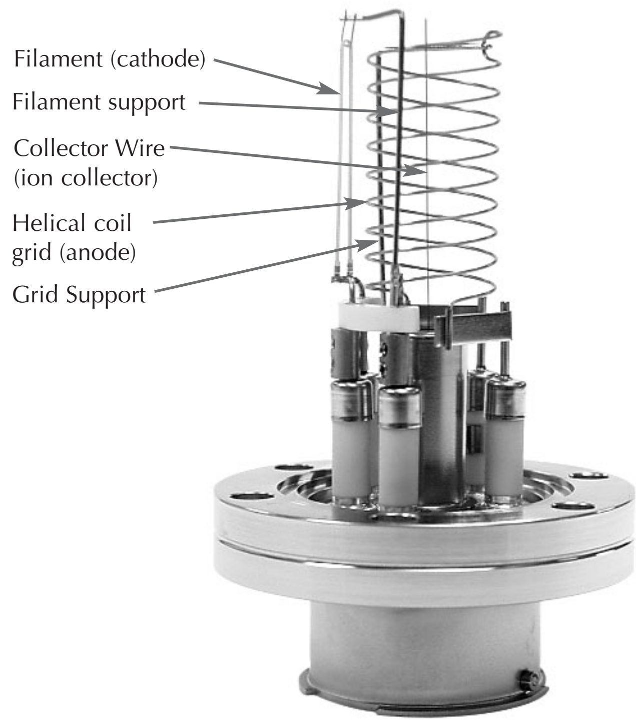
There are two types of materials commonly used for filaments: tungsten and iridium. And, there are two types of coatings used on the filaments: thoria and yttria.

Generally, filaments are yttria-coated iridium, thoria-coated iridium, or uncoated tungsten. The most common style is coated iridium because they operate at a lower temperature than tungsten, therefore less reactive. Coated iridium filaments are also more burnout resistant when exposed to atmospheric pressure while power is on. Tungsten filaments will burn out immediately if exposed to pressures of 1 x 10^{-2} Torr or higher while they're on. However, tungsten filaments are the best type to use when the chemistry (such as halogen compounds) of the vacuum process causes premature failure of coated iridium filaments.

The amount of emission current that a B-A gauge requires for proper operation depends on many factors such as: the size or style of the gauge, the process in which the gauge is used, the pressure range of operation, and the desired accuracy of the indicated pressure. Emission currents are typically in the range of 25 μA to 10 mA.



UHV Nude Bayard-Alpert Gauge
with dual tungsten filaments



Nude Bayard-Alpert Gauge
with thoria-coated iridium filament

Degassing Bayard-Alpert Gauges

The deposition of elements or compounds on exposed gauge surfaces can result from some processes, such as sputtering or coating operations. Water vapor is another compound that can collect inside the gauge when a vacuum chamber is exposed to atmosphere. During normal operation these materials will slowly come off the gauge surfaces, increasing the local pressure in the gauge. To more rapidly get the pressure in the gauge in equilibrium with the pressure in the chamber, "degassing" can be used to drive the molecules on the inner walls and surfaces from the gauge back into the chamber where they can be pumped out of the system. Degassing can be done as required or as part of a regular pumpdown sequence. Regular degassing helps prevent process deposits from collecting and allows the gauge to provide lower and more repeatable pressure indications by bringing the pressure in the gauge closer to equilibrium with the chamber.

There are two types of degassing techniques: Electron Bombardment (EB) and Resistive (I^2R). EB degas must be used for UHV nude gauges with fine wire mesh grids and can also be used for glass or nude gauges with helical coil grids. I^2R degas can only be used for gauges with helical grids.

Although similar in result, each degassing technique employs a different mechanism to perform this beneficial function. EB degassing is accomplished by increasing the anode voltage and the emission current to bombard the gauge with electrons of sufficient quantity and energy to displace deposited molecules. I^2R degassing is accomplished by passing current through the grid (anode) at a sufficient level to raise the grid temperature to displace the molecules.

Cleaning a gauge with solvents is not recommended. However, if a gauge has been exposed to silicone-based pump oil, solvent may be needed to remove the oil. If solvent is used, the gauge must be thoroughly dried before installing it back on the system and operating or degassing it.

Summary

Bayard-Alpert ionization gauges are hot-filament style devices used to measure pressures below 1 x 10^{-3} Torr. Recent developments in this technology have improved the accuracy of these devices at these pressures to the 4% to 6% range, improved the performance relative to the x ray limit, and provided greater reliability with more options for filament materials. In addition, degassing techniques allow B-A gauges to provide lower and more reliable pressure readings. The Granville-Phillips Stabil-Ion Gauge from Brooks Automation, Inc. provides all of these benefits, resulting in truly advanced vacuum measurement.

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