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CERAMIC-METAL IONIZATION GAGES

by

J. M. Lafferty

Report No. 56-RL-1655 November 1956

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Published by
Research Information Section
The Knolls
Schenectady, New York

ABSTRACT

Several metal-ceramic ionization gages which may be baked out at 700°C are described. One gage has electrical characteristics identical with those of the glass VG-1A, and is circuit-wise interchangeable with the VG-1A. A Bayard-Alpert ceramic ionization gage with a sensitivity of 0 7 that of the VG-1A is described for making very low pressure measurements Several new ceramic ionization gages consisting of cylindrical magnetrons which operate near cutoff are described These gages have end plates, maintained at a negative potential relative to the cathode, which collect the ion current and prevent the escape of electrons. One of these gages draws less than 50 microamperes of electron emission and measures only 5/8 in. in diameter by 1-3/8 in. long, yet has an ion current output equal to that of the conventional gage operating at the same pressure. The magnetic field is supplied by a cylindrical Alnico V magnet which slips over the gage and measures only 1-1/4 in in diameter and 1-3/8 in. long Soft x-ray generation by electrons striking the anode is kept at a minimum by the low cutoff magnetron current This reduces the photoelectric emission from the ion collector permitting the magnetron gage to measure pressures as low as 5×10^{-13} mm of Hg

CERAMIC-METAL IONIZATION GAGES

J M. Lafferty

INTRODUCTION

The ionization gage, in the form of a simple triode tube structure, is one of the oldest,[1] and still the most important, devices for measuring gas pressure under high vacuum conditions. In this gage, electrons from a thermionic cathode are accelerated through a positive grid structure If the accelerating voltage is greater than the ionizing potential of the gas, there is a finite probability that the electrons will ionize the gas molecules on colliding with them For a given geometry and a constant grid voltage and electron current, the number of positive ions formed is, for low pressures at least, proportional to the gas pressure A constant fraction of these ions may be collected by an electrode which surrounds the grid and is negative with respect to the cathode. A measure of the resulting ion current gives an indication of the gas pressure The sensitivity of such a gage may be defined as the positive ion current per unit of electron current per millimeter of gas pressure.

$$S = I_i / I_e p \qquad (1)$$

Obviously this sensitivity will depend upon the nature of the gas present and the electrode geometry and voltages

It is evident that if the gage is modified in such a way that the electrons travel in longer paths before they are collected by the grid, the probability of them colliding with and ionizing a gas molecule will be greatly enhanced and the sensitivity of the gage will be improved One way of increasing the path length of the electrons is to place the gage in a magnetic field Many workers[2] have tried this with varying degrees of success

DESIGN CONSIDERATIONS

The gage to be described here was designed with several specific objectives in mind. It was mounted on a single header so that it could be sealed directly into the device on which pressure measurements were to be made The header was to be sealed in with

silver-copper eutectic solder and titanium hydride This required that the seals and gage assembly withstand a temperature of at least 850°C It was desirable that the gage have a small volume and that the electron current be kept low in order to produce a minimum disturbance on the gas pressure measurements It was also desirable that the gage measure transient pressures in the presence of a varying magnetic field

The high-temperature conditions were met by making the gage header of forsterite ceramic and mounting the electrodes on titanium posts sealed directly to the ceramic In order to retain a moderate ion current output and still keep the gage small in size and the electron current low, requires that the electrons do an efficient job of ionizing This was accomplished by applying a magnetic field to the geometry shown in Fig 1 It consists of a cylindrical magnetron which is operated at cutoff The cylindrical anode is 3/8 in. in diameter and 5/8 in. long Two plates at the ends of the anode, with a negative voltage relative to the filament, act as ion collectors. The ionization of gas in a tube having a geometry of this type was first investigated by A W Hull in the early nineteen twenties [3] More recently this geometry has been applied to an ionization gage structure described by Conn and Daglish [4]

PERFORMANCE

In the arrangement shown in Fig 1, electrons emitted by the tungsten filament spiral around the axial magnetic field in the region between the negative ion collector plates If the magnetic field is sufficiently high most of the electrons fail to reach the anode and return to the cathode region. Some of the electrons may make many such orbits before being collected The electron density is therefore increased by the presence of the magnetic field and the probability of ionizing the gas is considerably increased This is illustrated in Fig 2 where the ion current and electron current are plotted as a function of the magnetic field The notation used in this and the following curves is

E_p = anode voltage

E_c = ion collector voltage

I_p = electron current to anode with no magnetic field applied

I_{Hp}= electron current to anode with a magnetic field applied

I_c = ion current

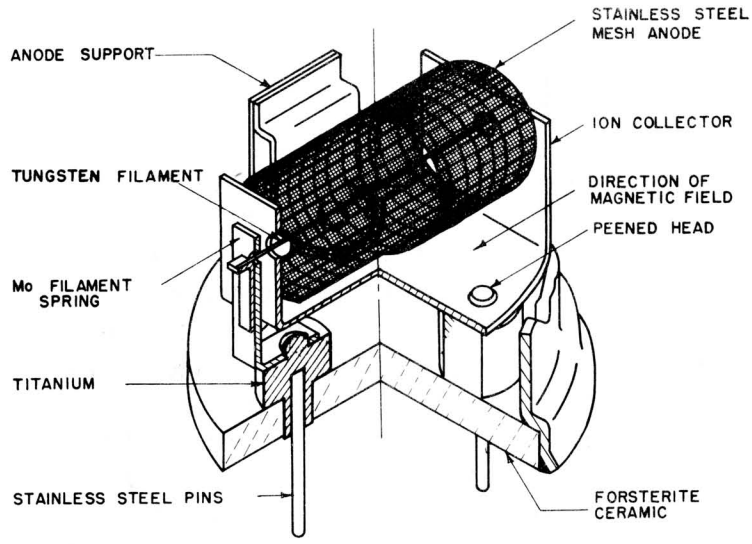


Fig. 1 Magnetron-type miniature ionization gage mounted on a ceramic header.

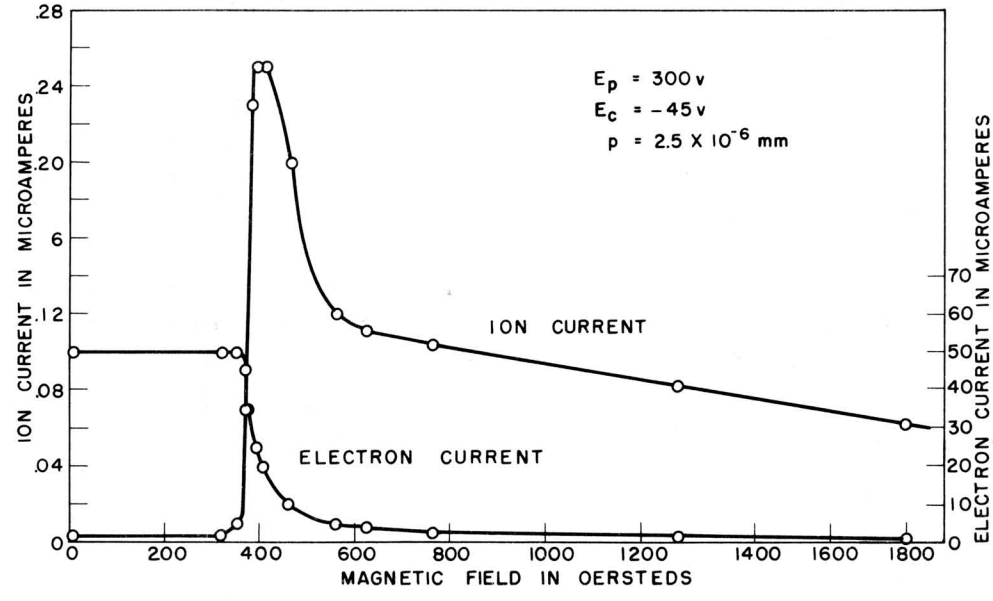


Fig. 2 The electron and positive ion current of the magnetron-type gage as a function of the applied magnetic field.

H = magnetic field in oersteds

p = gas pressure in millimeters.

Figure 2 shows that, for small values of magnetic field, the ion current is very low when the electrons flow straight out from the filament and strike the anode. As the magnetic field is increased and the electrons begin to miss the anode and return to the cathode region, their path length is increased, as indicated by the sharp rise in the ion current and a drop in the electron current collected by the anode At the optimum value of the magnetic field, the ion current is enhanced several orders of magnitude over what it would be without the field, and the electron current collected drops to about 1/10 the zero field value for the pressure shown When the magnetic field is increased beyond the cutoff value, the electrons travel in smaller spirals and are confined to a smaller volume, thus decreasing the probability of their making ionizing collisions As a result of this effect, the ion current drops slowly with increasing magnetic field If the gage is operated in a high magnetic field, say 1, 500 oersteds, there is some loss in sensitivity, however this sensitivity will not be altered appreciably by the superposition of a small stray varying magnetic field. This offers the possibility of measuring transient pressure conditions in the presence of varying magnetic fields

The ionizing region of this magnetron gage has only 1/10 the volume of the standard VG-1A and operates at 1/100 the electron emission, yet the ion current output is the same as that of the VG-1A at the same pressure

Figure 3 shows how the ion current varies as the electron emission current is increased by raising the filament temperature As the electron density is increased, the number of ions generated increases also In fact, for very low electron densities, the ion current is proportional to the electron current However, at higher electron densities some of the electrons gain energy due to collisions with one another [5] If this gain in energy expressed in electron volts exceeds the negative voltage on the ion collector plates, the number of electrons may exceed the number of ions striking the plates, thus causing the current to reverse in direction. At still higher electron densities the electrons rotate about the filament as a solid cloud[6] with a nearly uniform angular velocity given by

$$\omega = eH/2m = 8\ 8 \times 10^6\ H \text{ rad/sec} \qquad (2)$$

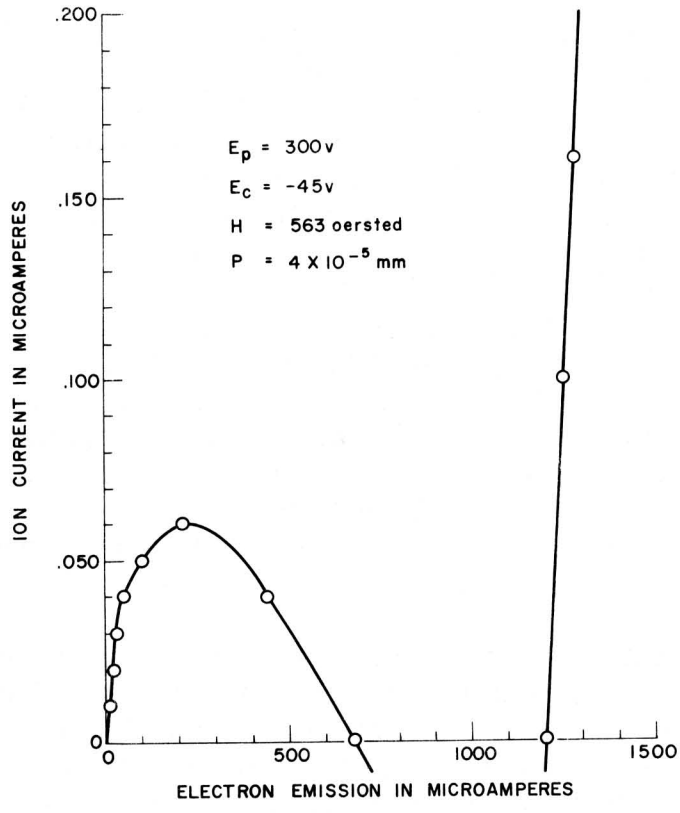


Fig. 3 Variation in the positive ion current of the magnetron-type gage as a function of the electron emission current

Under these conditions, there is, again, little chance of electronic collisions, and the ion current increases rapidly with the electron density

Figure 4 shows an interesting effect which results from collisions between the electrons and gas molecules at various pressures In these curves the magnetron cutoff current I_{Hp} is plotted as a function of the gas pressure for various values of constant electron emission I_p These data were taken on the magnetron gage shown in Fig 6 It will be noted that, at very low pressures, the cutoff current approaches a constant value independent of pressure and dependent only on the value of the electron emission. These small currents of constant value may be looked upon as a leakage current due to electrons with abnormally high velocities These high velocities are attributed to the conversion of some of the orbital energy of

the electrons into energy of random motion by collisions between electrons moving away from and returning towards the cathode[5] and to a lesser extent by initial thermal emission velocities. Thus the leakage current at low emission densities may be expected to be proportional to the electron emission as shown in Fig 4 As the pressure increases, the electrons begin to collide more frequently with the gas molecules These collisions may be both elastic and inelastic For 300-volt electrons in nitrogen, there will be about twice as many elastic collisions as ionizing collisions In these collisions the electrons lose none or only a small fraction of their total energy at each collision and rebound in directions which enable a large fraction of them to reach the anode. Some of the electrons may rebound in directions which prevent them from reaching either the cathode or anode These electrons are trapped in the interaction space until they lose so much energy in electron-electron collisions that they can reach the anode or gain enough energy to return to the cathode

Figure 5 shows the ion current collected as a function of pressure for various values of constant electron emission I_p Because of the logarithmic potential distribution between the cathode and anode, most of the ionizing collisions occur in a region which is nearly at anode potential Thus, very few of the secondary electrons ejected by the ionizing collisions will gain sufficient energy to do any ionizing before reaching the anode This is confirmed by the linearity and 45° slope of the ion current vs pressure curves in Fig 5 The 45° slope shows that the number of ionizing collisions is proportional to the gas pressure The curves are equally spaced vertically indicating that the number of ionizing collisions is also proportional to the electron emission. At pressures of 10^{-4} mm of Hg the electrons make many collisions before being collected This results in the electrons having low velocities during the latter part of their flight and hence lower ionizing efficiencies resulting in a flattening off of the ion current vs pressure curves at high pressure end

The ionizing efficiency[7] is defined as the number of ion pairs (a singly charged positive ion and one electron) produced by an electron per centimeter of path length in traveling through a gas at 1 mm pressure and 0°C Hence

$$S_e = n/Lp \quad , \tag{3}$$

where n is the number of ion pairs produced, L the length of path in centimeters traveled by an electron before being collected and p is the gas pressure in millimeters. If it is assumed that in an ionization gage

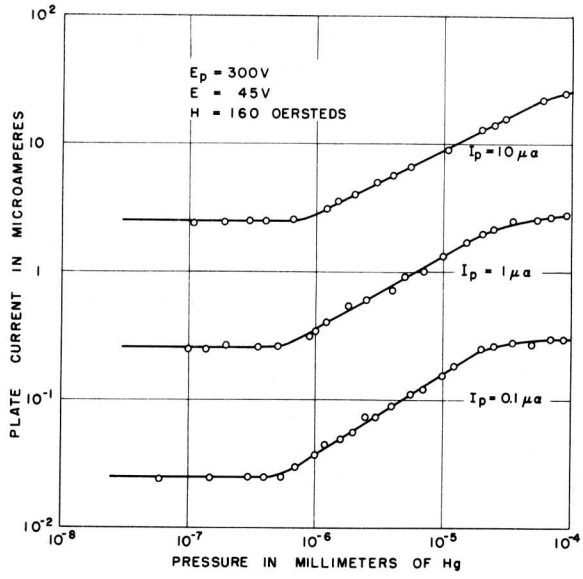
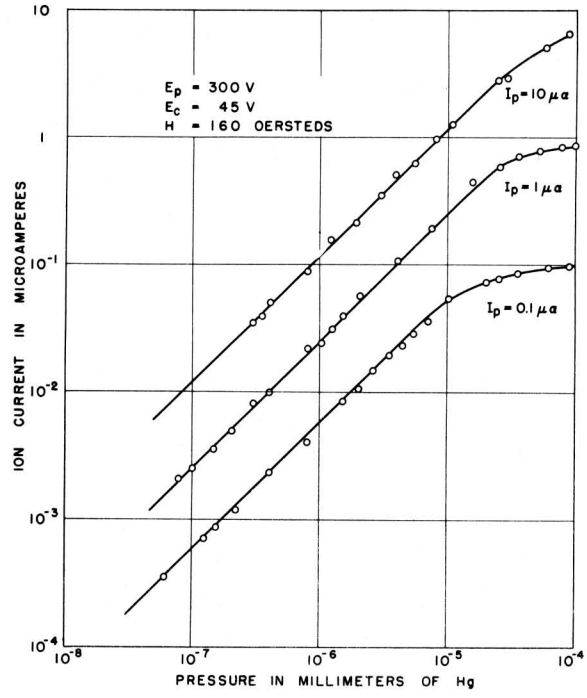


Fig 4 The electron cut-off current as a function of the gas pressure for a magnetron-type ionization gage

Fig 5 The ion current as a function of the gas pressure for a magnetron-type ionization gage



the number of ions produced per electron is equal to the ratio of the ion current to the electron emission current, it follows that

$$S_e = I_i / I_e \; Lp \tag{4}$$

This assumption is not strictly true There are more ions formed in the gage than reach the ion collector The ion collector collects only a constant fraction of the total ions produced The remainder of the ions are collected by the filament and the shield. The L computed by using Eq (4) may be thought of as an effective path length The ionizing efficiency depends on the nature of the gas and the velocity of the primary electron. For 300-volt electrons in nitrogen, $S_e = 8$ Substituting Eq (1) in Eq (4) and solving for L gives the effective path length of the electrons.

$$L = S/S_e \tag{5}$$

Also substituting Eq (5) in Eq (3) gives the average number of ionizing collisions occurring for each electron.

$$n = Sp \tag{6}$$

In Fig 5 it can be seen that for the $I_p = 0$ 1 μa curve, the sensitivity as calculated from Eq. (1) is S = 60,000 per millimeter If this is substituted in Eq (5), it gives a value of 7,500 cm for the effective path length At a pressure of 10^{-4} mm where the sensitivity of the gage has dropped appreciably, it is found on substituting the numerical values in Eq (6) that n = 6 collisions per electron. Since the energy lost at each ionizing collision is of the order of 80 volts on the average,[8] the electrons will certainly have lost nearly all of their kinetic energy when collected by the anode

LOW PRESSURE LIMITATIONS

The lowest pressure which most ionization gages may be expected to measure is determined by a spurious background current to the ion collector electrode. This current may be due to electrical leakage or photoelectric emission from the ion collector The photoelectric emission is caused by soft x-rays generated by the impact of the electrons on the grid and to a lesser extent by light from the incandescent filament The photoelectrons leaving the ion collector cannot be distinguished by the external measuring circuit from the positive ions striking it

In most cases, special precautions may be taken in designing the gages with proper insulation or guard rings so that electrical leakage is not a limiting factor This then leaves the photoelectric emission from the ion collector as the remaining problem

The photocurrent is proportional to the electron current which strikes the grid The proportionality constant is given by the product of the average number of x-ray photons emitted per collected electron and the probability that they will hit the ion collector and produce photoelectrons An obvious way to reduce the probability that the x-ray photons will strike the ion collector is to reduce its area This has been done in the Bayard-Alpert gage [9] The collector is made in the form of a wire of small diameter with a surface area about 200 times less than that of the conventional gage This electrode is placed in a position with respect to the other electrodes to maintain a high ion collection efficiency

The low pressure limit for the gage shown in Fig 1 is determined by the electrical leakage across the surface of the ceramic header In most cases this leakage will be in the neighborhood of 0 001 microampere, so that pressures as low as 10^{-8} millimeters of mercury can be measured This however, does not represent the lowest pressure which the magnetron-type gage is capable of measuring; it has the potential possibility of going to much lower values because of the low electron current Figure 4 shows that if the emission current is set at 1 0 microampere, the anode current will be about 0.25 microampere at pressures below 10^{-7} mm pressure. Under these conditions Fig 5 shows the ion current to be 1/4 that of a VG-1A This residual electron current to the anode of the magnetron gage is 20,000 times less than the 5 milliamperes drawn by the grid of the VG-1A The magnetron gage operates with 300 volts on the anode This is twice the voltage applied to the grid of the VG-1A The area of the ion collector in the magnetron-type gage is about 1/4 that of the VG-1A collector The soft x-ray output at the anode is proportional to the product of the electron current collected by approximately the square of the anode voltage The photoelectric emission from the ion collector will be proportional product of the area of the ion collector and the soft x-ray output from the anode From these data it may be calculated that the photoelectric emission current from the ion collector of the magnetron-type gage will be 20,000 times less than that from the VG-1A collector Thus the magnetron-type gage should be capable of measuring pressures as low as 5×10^{-13} mm

In order to evaluate the magnetron-type gage for measuring very low pressures, a special ceramic structure was made as shown in Fig 6 In this gage the ion collector lead was brought out through a ceramic bushing designed to give low leakage current This bushing is mounted on a titanium disk which may be used as a guard ring, giving additional protection against leakage The ion collector is in the form of a 0 005 in thick molybdenum disk placed at one end of the anode cylinder which is 15/16 in in diameter and 1 in. long At the other end of the anode cylinder is a similar disk which is connected to one leg of the filament or is biased slightly negative with respect to the filament. These two disks keep the electrons from escaping out of the anode region With this electrode design pressures as low as 10^{-11} mm have been measured Alpert[10] has suggested that the ultimate vacuum obtained in a sealed glass system is limited by the diffusion of atmospheric helium through the glass into the system Since the permeation of helium through a crystalline ceramic is less than that through fused glass,[11] it should be possible to obtain a better vacuum in a sealed all metal-ceramic system

CONSTRUCTIONAL DETAILS

The construction of the gage shown in Fig 1 is quite simple In this design the electrodes are all mounted on a forsterite-ceramic disk which forms a combination header and miniature tube base for the gage. The electrodes and supports are peened onto the titanium posts which in turn are sealed to the ceramic disk. The sealing is done in argon at atmospheric pressure After the sealing operation, the stainless steel mesh anode cylinder is spot-welded in place and the 8 mil tungsten filament is threaded into position and spot-welded to the filament supports This assembly is then ready for use It may, for example, be made an integral part of a tube structure by sealing it directly into the tube with titanium hydride and BT silver solder at the time the tube is exhausted and sealed

The anode is made of an open mesh to give a quick response to transient pressures Figure 7 shows a photograph of this gage before sealing into a stainless steel envelope A horseshoe magnet with soft iron pole pieces is used to supply the magnetic field in this case The constructional details, a working drawing and the details of the magnet and socket connections are given in Memo Report No P-79, "Miniature Ionization Gage on a Ceramic Header."

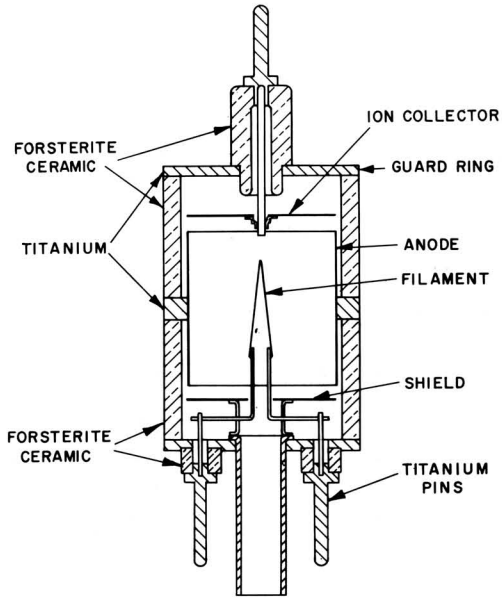


Fig. 6 Magnetron-type ionization gage for measuring very low pressures.

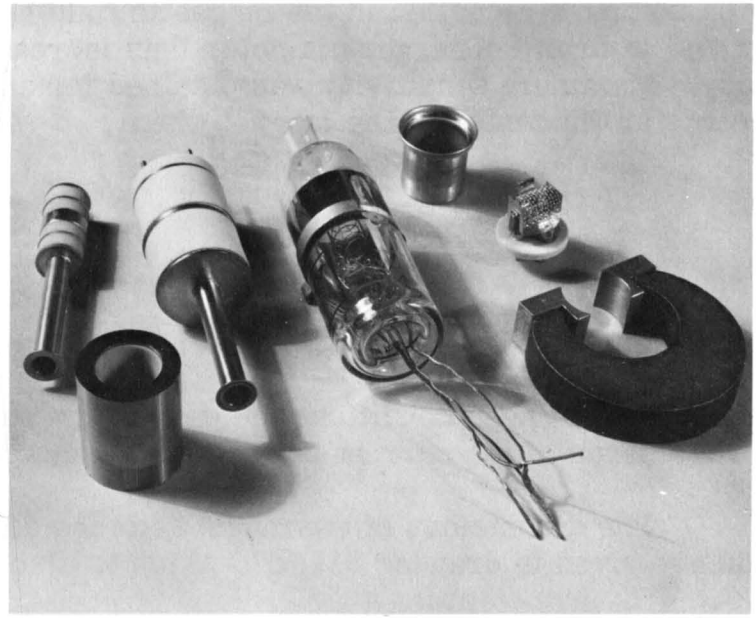


Fig. 7 Photograph of several ceramic ionization gages and a standard glass VG-1A.

A modified design of this gage is shown in Fig 8 The geometry is the same as before, but the construction has been changed for a special application The molybdenum anode cylinder is spot-welded to the titanium ring which supports it The filament support strap is spot-welded to a titanium washer which forms the opposite end of the gage. These parts are then stacked up with forsterite ceramic rings which serve to insulate the parts and form the gage envelope This assembly is then clamped together and heated to 1050°C in argon at atmospheric pressure to make the ceramic-metal seals and braze the stainless steel parts to the titanium. The filament tension spring and filament are then inserted into the gage through the tubulation. The spring is compressed, and the filament is arc welded to the filament support tube in a hydrogen atmosphere. Complete constructional details for this gage may be found in working drawing 285C559 which is included in Memo Report No P-78, "A Miniature Ceramic Ionization Gage."

The magnetic field for this gage is supplied by a cylindrical Alnico V permanent magnet This magnet is magnetized in a direction parallel to the axis of the cylinder so that some of the magnetic lines thread through the center of the cylinder and, hence, through the gage as well as around the outside It was found that maximum sensitivity was obtained for the gage when the length of the magnet was made equal to the length of the gage This gives a divergent magnetic field which is weaker at the ends of the anode cylinder than at its center The negative collector plates at the ends of the anode reduce the radial electric field in this region so that a reduction in the magnetic field here permits the electrons to travel in orbits of larger diameter thus increasing their ionizing efficiency Maximum sensitivity was obtained for a field strength of 450 oersteds at the center of the magnet when

$$E_p = 300 \text{ v} ,$$

$$E_c = -45 \text{ v} ,$$

and $$I_p = 50 \ \mu\text{amps (for zero magnetic field)}$$

Under these conditions the sensitivity was approximately 30 microamperes of ion current per micron of gas pressure

The dimensions of the magnet and the details of the connector leads are given in drawing 311B570 which is also included in Memo Report P-78.

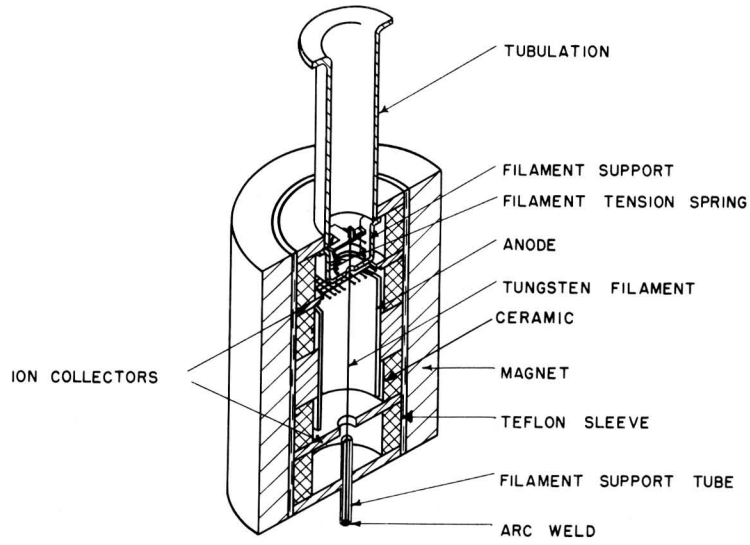


Fig 8 Magnetron-type miniature ionization gage with cylindrical magnet

The electrode voltages, except for the filament, may be supplied by dry cell batteries since the current drain is very low Figure 9 shows a simple a-c power supply used to operate the gage An RCA model WV-84A microammeter is used to measure the ion current. Multiplying the ion current in microamperes by 3×10^{-5} gives the gas pressure in millimeters of mercury Figure 7 also shows the gage with its cylindrical magnet

OTHER TYPES OF CERAMIC IONIZATION GAGES

In addition to the magnetron-type gages described above, several other types have been made for various applications These include ceramic versions of the standard VG-1A and the Bayard-Alpert type for measuring very low pressures All of these gages can be baked out at high temperatures

Figure 10 shows a ceramic VG-1A This gage has an envelope of forsterite ceramic and titanium The stainless steel tubulation has a flare which may be welded to the device on which pressure measurements are to be made The inside of the gage consists of the usual triode arrangement with a tungsten filament, a tungsten grid operated at a positive potential for accelerating the electrons up to ionizing velocities and a negative collector cylinder for collecting a fraction of the positive ions thus formed A measure of the resulting ion

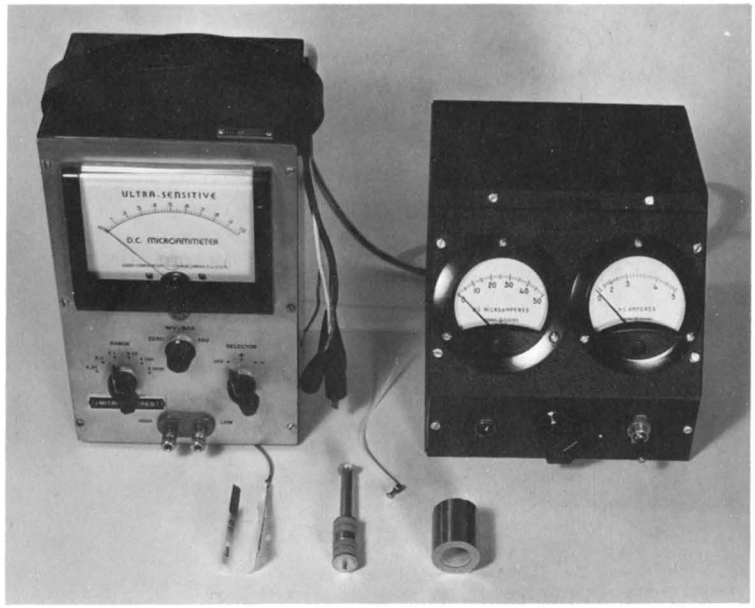


Fig. 9 A-c power supply and micro-ammeter used with ceramic magnetron-type ionization gage.

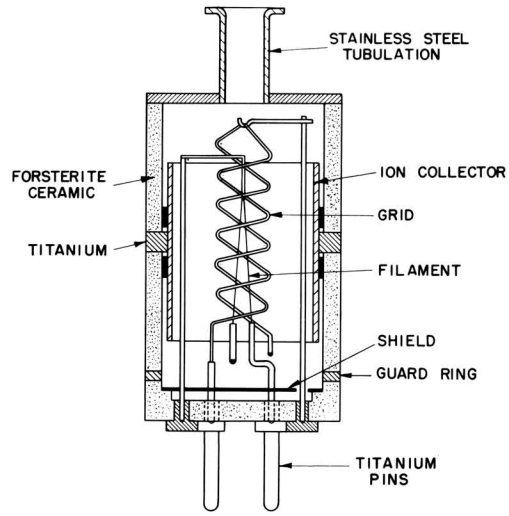


Fig. 10 VG-1A type ceramic ionization gage.

current gives an indication of the gas pressure. This gage was designed so that its electrical characteristics are identical with those of the glass VG-1A. This has the advantage that the commercially available amplifying and control circuits may be used with the ceramic gage without modification. A photograph of this gage is shown in Fig. 7

A modification of this triode structure is shown in Fig. 11. Here the entire gage assembly is mounted on a ceramic header which may be sealed directly into the device in which pressure measurements are to be made. The electrical characteristics of this triode structure are also identical with those of the VG-1A. The construction and operation of these two gages are described in Memo Report No. P-80, "VG-1A Type Ceramic Ionization Gages."

A ceramic Bayard-Alpert gage is shown in Fig. 12 This gage fits into the same size envelope as the ceramic VG-1A and has a sensitivity of 0.75 that of the VG-1A. Complete constructional details and operation of the ceramic Bayard-Alpert gage may be

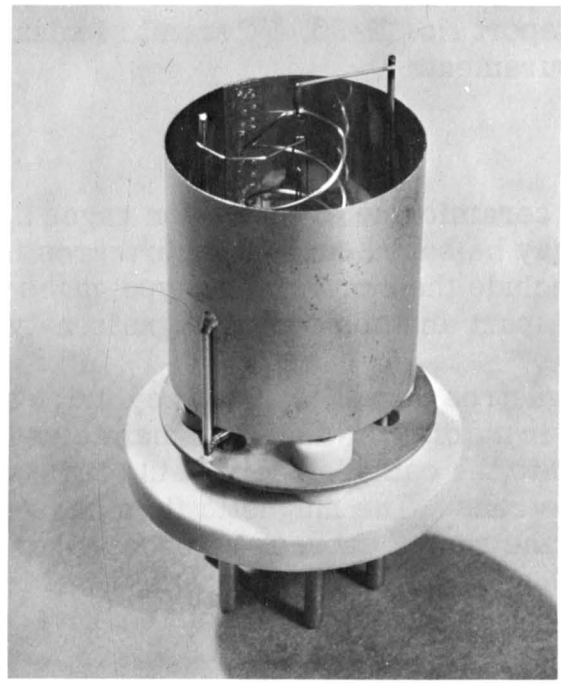


Fig. 11 VG-1A type ionization gage mounted on a ceramic header.

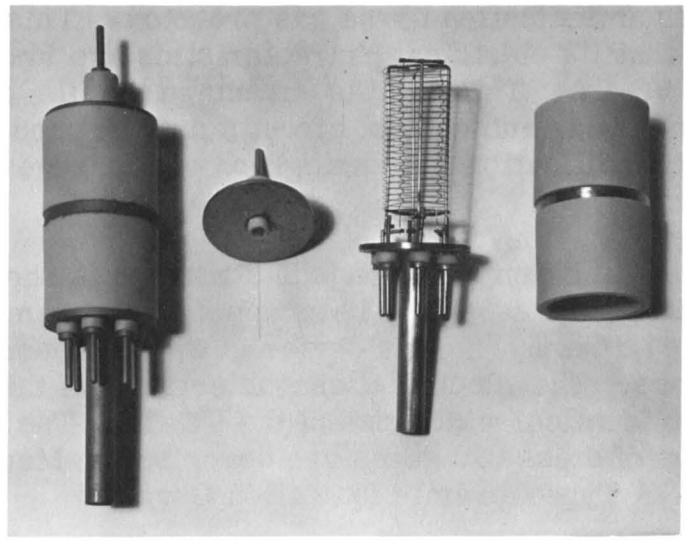


Fig. 12 Bayard-Alpert ceramic ionization gage for measuring very low pressures. A completed gage is shown on the left.

found in Memo Report No. P-96, "Ceramic Ionization Gages for Ultra-High Measurements "

SUMMARY

Several ceramic-metal ionization gages have been constructed which may be baked out at temperatures in the range of 700°C. These include the conventional type gages such as the VG-1A and the Bayard-Alpert and some new magnetron-type gages.

The magnetron gages consist of cylindrical magnetrons which operate near cutoff. End plates, maintained at a negative potential relative to the cathode, collect the ion current and prevent the escape of electrons. The magnetic field causes the electrons to spiral around in the region between cathode and anode thus increasing their path length. This increases the ionizing efficiency of the electrons permitting the construction of sensitive gages of relatively small dimensions. Because of the low electron current collected by the anode, the photoelectric emission from the ion collector due to soft x-rays is reduced, thus enabling the magnetron gage to measure pressures as low as 10^{-12} mm of Hg.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the help of E. L Bahm, A R. Kolasinski, and J J. Keenan in the construction of these gages We are indebted to A. G. Pincus and his group for many discussions on ceramic problems and for supplying the titanium-matching forsterite ceramics. L J Favreau and C P. Goody assisted in taking data on the performance of the gages

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TO Paine

Measurements and Industrial Products Division (continued)

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GENERAL ELECTRIC

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SCHENECTADY, NEW YORK

TECHNICAL INFORMATION SERIES

Title Page

AUTHOR	SUBJECT CLASSIFICATION	NO.
Lafferty, J. M.	ionization gages	56-RL-1655
		DATE: November 1956

TITLE

Ceramic-Metal Ionization Gages

23-205

ABSTRACT: Several metal-ceramic ionization gages which may be baked out at 700°C are described. One gage has electrical characteristics identical with those of the glass VG-1A, and is circuit-wise interchangeable with the VG-1A. A Bayard-Alpert ceramic ionization gage with a sensitivity of 0.7 that of the VG-1A is described for making very low pressure measurements. Several new

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3	Research Information Section, The Knolls Schenectady, New York	18
GOV CLASS		

~~CONCLUSIONS~~

ceramic ionization gages consisting of cylindrical magnetrons which operate near cutoff are described. These gages have end plates, maintained at a negative potential relative to the cathode, which collect the ion current and prevent the escape of electrons. One of these gages draws less than 50 microamperes of electron emission and measures only 5/8 in. in diameter by 1-3/8 in. long, yet has an ion current output equal to that of the conventional gage operating at the same pressure. The magnetic field is supplied by a cylindrical Alnico V magnet which slips over the gage and measures only 1-1/4 in. in diameter and 1-3/8 in. long. Soft x-ray generation by electrons striking the anode is kept at a minimum by the low cutoff magnetron current. This reduces the

(continued on following page)

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INFORMATION PREPARED FOR:

SECTION: Physical Studies

DEPARTMENT: General Physics Research

Abstract(continued)

photoelectric emission from the ion collector permitting the magnetron gage to measure pressures as low as 5×10^{-13} mm of Hg

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