

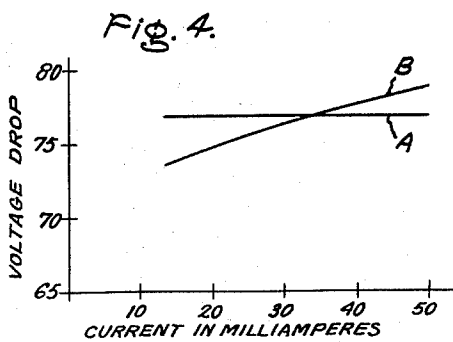
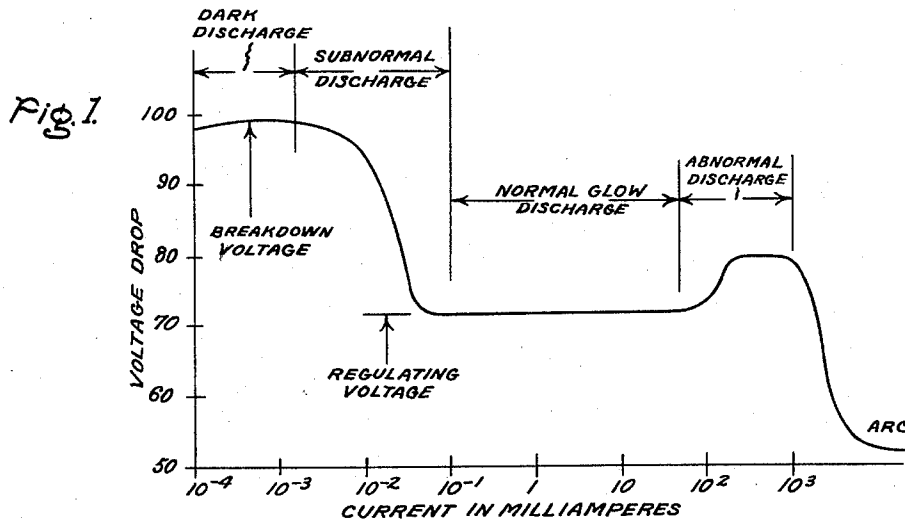
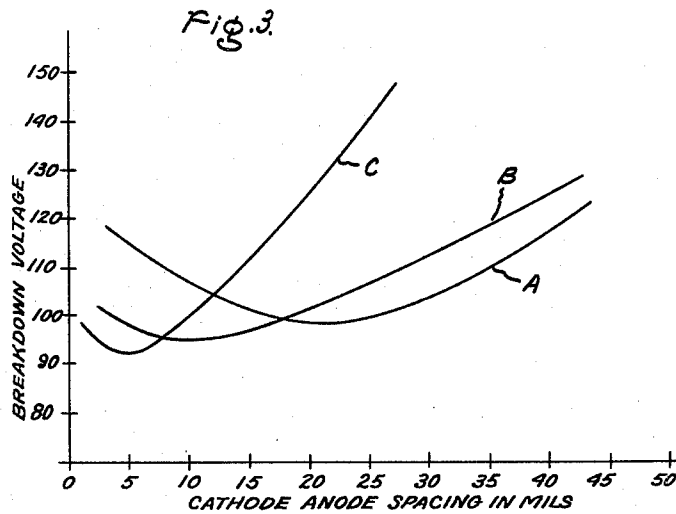
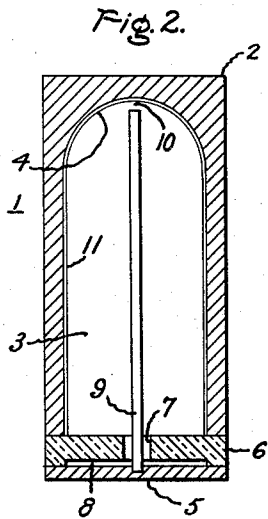
July 5, 1960

J. M. LAFFERTY

2,944,179

GASEOUS DISCHARGE DEVICE

Filed Oct. 17, 1957



Inventor:
James M. Lafferty,
by Paul A. Frank
His Attorney.

1

2

2,944,179

GASEOUS DISCHARGE DEVICE

James M. Lafferty, Schenectady, N.Y., assignor to General Electric Company, a corporation of New York

Filed Oct. 17, 1957, Ser. No. 690,847

10 Claims. (Cl. 313-214)

The present invention relates to gaseous electric discharge devices. More particularly, the invention is directed to improved voltage regulator tubes.

Voltage regulator tubes are two element cold cathode gas tubes which are ionized and become conducting at a voltage denominated as "breakdown voltage" and sustain a glow discharge having a constant potential difference between the electrodes thereof over a substantial range of current. Although, ideally, this potential difference or "regulating voltage" is constant, as a practical matter, it may vary as much as 0.57 volt per milliamper in commercial voltage regulator tubes. This variation is due, in part, to poor electrode geometry, and to impurities in the gas and the electrodes used.

Accordingly, one object of the present invention is to provide a voltage regulator gaseous discharge device having a substantially constant regulating voltage over a substantial current range.

A further object of the invention is to provide a voltage regulator gaseous discharge device having a heretofore unobtainable current operating range.

Another object of the invention is to provide a high temperature voltage regulator gaseous discharge device.

Still another object of the invention is to provide a voltage regulator gaseous discharge device having a minimum breakdown voltage characteristic.

In accord with the present invention I provide a noble gas filled voltage regulator gaseous discharge device comprising a hollow cylindrical cathode cavity terminating in a smoothly curved concave surface, and an elongated rod-like anode having a diameter much less than that of the cathode cylinder inserted concentrically therein. The end of the anode rod is closely spaced from the end of the cathode cavity defining a gap therewith, the dimension of which causes breakdown of the device to occur substantially at the minimum of the Paschen curves for the gas and electrode material used. The continuous surface of the cathode provides for a uniform regulating voltage, and the increased cathode area provides for an increased range of operation.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof may best be understood by reference to the following detailed description taken in connection with the attached drawing in which:

Fig. 1 is a voltage-current characteristic of a voltage regulator tube constructed in accord with the present invention;

Fig. 2 is a vertical cross-section of a voltage regulator gaseous discharge device constructed in accord with the invention;

Fig. 3 is a graph showing typical Paschen curves for the device of Fig. 2, and

Fig. 4 is a graph comparing the characteristics of a voltage regulator tube of the invention with those of a conventional voltage regulator tube.

A voltage regulator tube is one in which the potential

difference between anode and cathode remains nearly constant over a considerable range of current. The characteristics of a voltage regulator glow discharge tube constructed in accord with the present invention are presented in Fig. 1 of the drawing wherein the characteristics are plotted in voltage as a function of current through the tube. A glow discharge is initiated when the potential between the anode and cathode reaches a "breakdown voltage." The characteristics which determine the value of breakdown voltage will be discussed in greater detail hereinafter. Once breakdown has occurred in the voltage regulator tube, a small amount of current may be passed causing discharges which are known as the "dark discharge" and "subnormal discharge," respectively. During these discharges, when the amount of current passed is maintained at a low value by the external circuit, a considerable amount of ionization of the gas in the tube is lost by diffusion of ions to the walls of the tube. As current increases, however, this diffusion is compensated, and a steady state condition is reached which is known as the "normal glow" discharge. During the normal glow discharge a constant value of current density is attained and, although greater amounts of current may be passed, the increase in current is attained by a spreading-out of the discharge over a larger area of the cathode at a constant current density. This means that a constant potential difference is maintained between anode and cathode.

It is the region of normal glow discharge which is utilized in the regulatory function of a voltage regulator tube. Once the amount of current passed through a voltage regulator tube has increased so that substantially all the cathode area is encompassed by the glow discharge, any further increase in current must be attained through an increase in current density. This increase in current density requires a greater potential difference between anode and cathode to sustain the discharge, and the potential difference between cathode and anode accordingly increases with increasing current beyond the normal glow discharge region, to cause the "abnormal glow" discharge. Further increases in current result in the formation of a cathode spot and the breakdown of the glow discharge into an arc discharge, with a relatively small potential difference between anode and cathode. The breakdown of a glow discharge into an arc discharge may be inhibited to some extent by the provision of cathode surfaces which are extremely clean and regular and by maintaining the distance between anode and cathode substantially greater than the distance between the cathode and the Faraday dark space in the characteristic glow discharge diagram for the gas and pressure utilized.

I have found that in order to maintain the normal glow discharge region of a voltage regulator tube at a substantially constant operating voltage throughout and to increase the current range over which normal glow discharge is maintained, the voltage regulator tube should be provided with a maximum possible cathode area for the size utilized, that the cathode surface should be maintained smooth and uninterrupted with an absence of sharp corners and protuberances and that the gas utilized in filling the tube should be of the greatest order of purity obtainable.

A voltage regulator tube constructed in accord with the present invention is illustrated in Fig. 2 of the drawing. In Fig. 2 a voltage regulator tube represented generally as 1 comprises a hollow elongated cup-shaped cathode block 2, generally cylindrical in shape having a cylindrical bore 3 therein, which bore terminates in a smoothly curved surface, preferably substantially hemispherical thus forming an end wall 4. The open end of the cathode block opposite hemispherical end wall 4 is closed with a metallic disk 5, which is spaced from the body of cathode block 2 by an annular disk of a ceramic

refractory insulating material having a central aperture 7 therein and an annular recess 8 in the outer surface thereof. A rod shaped anode 9 is mechanically supported in cantilever fashion at its lower end by end wall member 5 and extends through aperture 7 in ceramic disk 6. Conveniently, anode 9 is press fitted into a suitable aperture in the geometrical center of end wall member 5. Anode rod 9 is of a diameter which is very small in comparison with the interior diameter of cathode block 2, and is of such a length as to terminate at a very short distance from the interior end of hemispherical end wall 4 forming therewith a breakdown gap 10. In constructing the tube, a coating of a suitable cathode surface material may be initially present upon the surface of anode rod 9. During firing to form the tube seals this material is, however, evaporated and is spread evenly over the surface of cathode 2 to form a thin electron-emissive coating 11.

Cathode block 2 and end-wall 5 may be of any highly conductive material such as copper, but are preferably constructed of titanium. Titanium is used to obtain optimum characteristics from the device because of the unique gettering characteristics thereof. As is discussed briefly hereinbefore, I have found that one of the conditions necessary for the achievement of a substantially uniform potential difference between cathode and anode over a substantial range of operating currents of a voltage regulator tube is the maintenance of high gas purity. If any small quantity of chemically active gas other than the noble gas intended to be utilized is present within the tube the characteristic changes markedly with current and time. Accordingly, the voltage regulator tubes of the present invention are filled with an atmosphere of a noble gas or mixture of noble gases while the device is being sealed in accord with the invention disclosed and claimed in my copending application Serial No. 690,849 filed concurrently herewith and assigned to the present assignee.

In accord with my copending application, gaseous discharge devices which utilize a noble gas filling are formed by the sealing of titanium and titanium-matching ceramic members while the tube is maintained in an atmosphere of the operating gas at a suitable pressure. When titanium is heated to the temperatures (of the order of 700° C. to 1100° C.) at which titanium may be bonded to titanium-matching ceramics, the metal is an excellent getter for impurities commonly present in noble gases such as CO₂, H₂, H₂O, O₂, N₂ and the like. When the device of the present invention is so formed the resultant atmosphere consists of a highly purified noble gas. The noble gas utilized is, of course, dependent upon the voltage at which the tube is to be operated. Any of the stable noble gases, helium, neon, argon, krypton, xenon or mixtures thereof may be utilized with the same desirable effect, the gas chosen depending upon the voltage at which the device is to be operative. In view of the foregoing, it is apparent that unique and useful advantages accrue from the fabrication of cathode block 2 and end wall 5 from titanium.

Annular insulating member 6 is composed of a refractory ceramic, the coefficient of thermal expansion of which is a close match for that of titanium, and which hence, may be suitably bonded at high temperatures to form hermetic seals with titanium cathode block 2 and titanium end wall 5. Such a ceramic is a sintered agglomerate of silicon oxide, magnesium oxide and aluminum oxide denominated as Forsterite. One such Forsterite ceramic and the method of preparation thereof are disclosed and claimed in the copending application of A. G. Pincus, Serial No. 546,215, filed November 10, 1955, now U.S. Patent 2,912,340, granted November 10, 1959, and assigned to the assignee of the present invention.

Anode rod 9 is fabricated from a suitable metal which does not react strongly with titanium as for example, titanium, tungsten, stainless steel, molybdenum and other

metals conventionally utilized as electrodes in electron discharge devices. Since the regulating voltage of a voltage regulator tube is a function only of the nature of the cathode surface and of the gas utilized, anode rod 9 may initially be coated with a suitable coating which, upon operation of the tube, is evaporated therefrom to form a uniform coating upon the interior surface of cathode block 2. Thus, for example, if the regulator tube is designed to regulate at a voltage of approximately 75 volts a barium cathode surface together with an atmosphere of argon is suitable. In this instance, a coating several thousandths of an inch thick of barium aluminate may be placed upon anode rod 9 resulting, upon operation, in a thin film of barium-aluminum being deposited upon the interior surface of cathode block 2. Other materials which may be utilized as a coating upon anode rod 9 are cerium, magnesium and lanthanum. Alternatively, if, for example, a regulating characteristic of approximately 150 volts is desired, such a characteristic is achieved if the titanium which comprises cathode block 2 is utilized in conjunction with an argon atmosphere. Likewise, a regulating voltage of 180 volts may be achieved utilizing a cathode surface of titanium and an atmosphere of xenon. In these, and similar instances when the cathode surface is to be titanium, coating 11 is not formed. Suitable materials for cathode surfaces and combinations of these materials with noble gases or mixtures of noble gases for any desired regulating voltage will readily be apparent to those skilled in the art. In general, gaseous discharge devices constructed in accord with the present invention are filled with an atmosphere of a noble gas or a mixture of noble gases at a pressure of 5 to 40 mm. of mercury.

An important feature in the construction of devices in accord with the present invention is the annular re-entrant slot 8 in ceramic disk 6. Since the surface of the ceramic wafer bounded by this slot is, by virtue of the narrowness of aperture 7 in disk 6, completely shielded from glow discharge which occurs between cathode 2 and anode 9 this surface remains, during the operation of the tube, completely free of metal sputtered from the cathode. If provision were not made to keep a portion of the ceramic surface between cathode 2 and anode 9 completely free of metal, a leakage path would soon be formed between cathode and anode which would eventually cause partial or complete short-circuiting of the device.

As is briefly discussed hereinbefore, an important factor which I have discovered to be of great influence upon the maintenance of a uniform potential difference between anode and cathode in voltage regulator tubes, and for achieving a large range of current over which this uniform potential difference is maintained, is the maintenance of a maximum cathode area for the size device constructed, and the maintaining of this area smooth, continuous and homogeneous. In accord with the present invention, these conditions are satisfied by fabricating the cathode surface in the form of a smooth cylinder terminating in a smoothly curved end wall which is preferably substantially hemispherical. In the operation of the device gaseous breakdown first occurs at gap 10 defined by the extreme interior end of anode rod 9 and the adjacent portion of the interior surface of cathode 2. As the current passing between the cathode and the anode is increased, due to the external circuit parameters, the glow discharge formed at this region gradually and uniformly spreads out over the adjacent regions of the cathode until, at the maximum current which may be passed with a uniform potential difference, the glow discharge fills the entire region between anode 9 and cathode 2. Thus, by the simple configuration of cathode 2 and anode 9 utilized in the devices of the present invention, the potential difference between cathode and anode is maintained substantially constant over a range of current heretofore unobtainable in voltage regulator devices. As

may be seen from the curve of Fig. 1 this current range extends for 3 orders of magnitude.

A further advantage of the present invention is derived from the relationship of the breakdown gap 12 to the general configuration of cathode and anode. As is well known to the art, and expressed by Paschen's law the potential at which gaseous breakdown occurs between two electrodes in a particular atmosphere for that particular atmosphere and the material electrodes utilized is a function only of the product of the gas pressure and gap length. One may plot the well known Paschen curves, which are plots of breakdown voltage as a function of cathode-anode spacing for a given gas at a particular pressure. In Fig. 3 of the drawing, the Paschen curves for argon gas and a barium cathode surface are presented. As may readily be seen, from Fig. 3 wherein curves A, B and C are plotted for 10, 20 and 40 mm. pressure, respectively, there is, for each gas pressure, a particular cathode-anode spacing at which the breakdown voltage is a minimum. Since it is elementary that, for ideal operation of a voltage regulator tube, the breakdown voltage should approach the regulating voltage as nearly as possible, the breakdown gap 10 in the voltage regulator tubes of the present invention is adjusted so that the pressure-distance product is substantially equal to the minimum of the Paschen curve for the cathode material and the gas utilized at the pressure at which the tube is operated. As may be seen from Fig. 3 these ideal distances are of the order of from 0.005" to 0.020". This distance range is similar for all inert gases used. It may also readily be seen from a consideration of Fig. 2, which is drawn to scale, that the breakdown gap 10 is very small as compared with the radial distance between cathode 2 and anode rod 9. Thus, in the operation of the present devices breakdown invariably occurs at the breakdown gap 10 and, as operating current is increased, the glow discharge rapidly spreads out along the smooth surface of the interior surface of cathode block 2, the major portion of the regulating glow discharge occurring radially between cathode 2 and anode rod 9.

As an example of the useful improvements in voltage regulator gaseous discharge devices constructed in accord with the present invention reference is made to Fig. 4 of the drawing. Fig. 4 is a graphical representation of the voltage-current characteristics of an argon-filled voltage regulator gaseous discharge device having a barium cathode surface constructed in accord with the present invention (curve A) as compared with the voltage current characteristics of a standard VR-75 voltage regulator tube which is designed to regulate at a voltage of 75 volts (curve B). As may readily be seen from Fig. 2 the characteristic of the voltage regulator tube constructed in accord with the present invention is substantially constant from a value of 10 milliamperes to 50 milliamperes whereas the standard VR-75 tube varies from a potential of approximately 72 volts to approximately 80 volts over this current range. These advantages and this great improvement are attributable to the unique electrode configuration utilized in devices of the present invention together with the use of titanium metal as the cathode, thus facilitating fabrication of the tube in accord with my aforementioned copending application to achieve a gaseous atmosphere consisting of highly purified noble gas or mixtures of noble gases.

A further advantage of devices constructed in accord with the present invention is that since the only materials utilized are a metal, preferably titanium, and a refractory ceramic these devices are extremely rugged and impervious to a large amount of mechanical stress and thermal strain. Devices manufactured in accord with the present invention may be operated at temperatures from -70° C. to 500° C. without any substantial diminution of their desirable characteristics. Furthermore, these devices provide an optimum regulating characteristic with a minimum of size. Thus, for example, voltage regu-

lators tubes constructed in accord with the present invention designed to operate at operating currents up to 100 milliamperes and to regulate voltages as high as 200 volts have been constructed approximately $\frac{1}{2}$ " in diameter and 2" in length.

While the invention has been set forth hereinbefore with respect to certain embodiments and examples thereof, many changes and modifications will be obvious to those skilled in the art. Accordingly, I intend by the appended claims to cover all such modifications and changes as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A gaseous electric discharge device for maintaining a constant terminal voltage over a substantial range of current through the device comprising: a cup-shaped elongated metallic member having a deep cylindrical bore therein terminating in a smoothly curved concave surface forming an interior end wall therefor, the interior surface of said bore and said end wall providing a cathode surface for the device; a metallic end wall member hermetically sealed to the open end of said cup-shaped member in insulating relation therewith and supporting an elongated rod-like anode concentrically within said cylindrical bore, said anode terminating short of the smoothly curved end wall to provide a breakdown gap which is very small with respect to the radial distance between said anode rod and the interior surface of said cylindrical bore; and a highly purified noble gas atmosphere within said device.

2. The device of claim 1 wherein said cup-shaped member and said end wall member are of titanium.

3. A gaseous electric discharge device for maintaining a constant terminal voltage over a substantial range of current through the device comprising: a cup-shaped elongated metallic member having a deep bore therein terminating in a smoothly curved concave surface to form an interior end wall therefor, the surface of said cylindrical bore and of said end wall providing a cathode surface for the device; a substantially planar metallic end wall member closing the open end of said cup-shaped member and supporting therein an elongated rod-like anode concentric within said cylindrical bore, said anode terminating short of the smoothly curved end wall to provide a breakdown gap therewith the dimension of which is very small as compared with the radial distance between said anode rod and the interior surface of said cylindrical bore, a refractory ceramic disk having a central aperture therein to allow said anode rod to pass therethrough and an annular recess on the surface thereof nearest said substantially planar end wall interposed between said cup-shaped member and said substantially planar end wall and hermetically sealed thereto; and a highly purified noble gas atmosphere within said device.

4. The device of claim 3 wherein said cup-shaped member and said end wall member are of titanium.

5. A gaseous electric discharge device for maintaining a constant terminal voltage over a substantial range of current through the device and comprising: a cup-shaped elongated metallic member having a cylindrical bore therein terminating in a smoothly curved concave surface providing an interior end wall therefor, the interior surface of said cylindrical bore and of said end wall forming a cathode surface for the device; a metallic end wall member hermetically sealed to the open end of said cup-shaped member and in insulating relation therewith, said metallic end wall member supporting an elongated rod-like anode concentrically within said cup-shaped member, said anode terminating short of said smoothly curved end wall to provide a breakdown gap therewith of such dimension that the gas pressure-gap length product is substantially equal to the pressure-distance product for minimum breakdown voltage for the gas, pressure, and cathode sur-

7

face material utilized, and a highly purified noble gas atmosphere within said device.

6. The device of claim 5 wherein said cup-shaped member and said end wall member are of titanium.

7. A gaseous electric discharge device for maintaining a constant terminal voltage over a substantial range of current through the device comprising: a cup-shaped elongated member having a cylindrical bore therein terminating in a smoothly curved concave surface forming an end wall therefor, the interior surface of said cylindrical bore and of said end wall providing a cathode surface for the device; a substantially planar metallic end wall member sealed to the open end of said cylindrical bore and in insulating relation therewith, said metallic end wall member supporting an elongated rod-like anode concentrically within said cylindrical bore, said anode rod terminating short of the smoothly curved end wall and providing a breakdown gap therewith, the dimension of which is very small with respect to the radial distance between said anode and said cylindrical bore, a noble gas atmosphere within said device and a coating of barium on the interior surface of said cup-shaped member.

8. The device of claim 7 wherein said cup-shaped member and said end wall member are of titanium.

9. A gaseous electron discharge device for maintaining a constant terminal voltage over a substantial range of current through the device comprising: a cup-shaped elongated metallic member having a deep cylindrical bore therein terminating in a smoothly curved concave surface to provide an end wall therefor, the surface of said cylin-

8

drical bore and said smoothly curved end wall providing a cathode surface for the device; a substantially planar metallic end wall member closing the open end of said cup-shaped member and supporting therein an elongated rod-like anode concentrically within said cylindrical bore, said anode terminating short of the smoothly curved end wall to provide a breakdown gap of such dimensions that the gas pressure-gap length product is substantially equal to the pressure-distance product for minimum breakdown voltage for the gas, pressure, and cathode surface utilized; an insulating ceramic disk having a central aperture therein to allow said anode to pass therethrough and an annular recess in the surface thereof adjacent said substantially planar end wall interposed between said cup-shaped member and said substantially planar end wall and hermetically sealed thereto; a noble gas atmosphere within said device, and a layer of barium coated upon the interior surface of said cup-shaped member.

10. The device of claim 9 wherein said cup-shaped member and said end wall member are of titanium.

References Cited in the file of this patent

UNITED STATES PATENTS

25	2,104,784	Wiegand	Jan. 11, 1938
	2,414,450	Chevigny	June 17, 1947
	2,422,324	Watrous	June 17, 1947
	2,427,086	Arnott	Sept. 9, 1947
	2,656,478	Friedman	Oct. 20, 1953
30	2,747,125	Todd	May 22, 1956