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SPUTTER RESISTIVE COLD CATHODE FOR LOW PRESSURE GAS DISCHARGE DEVICE

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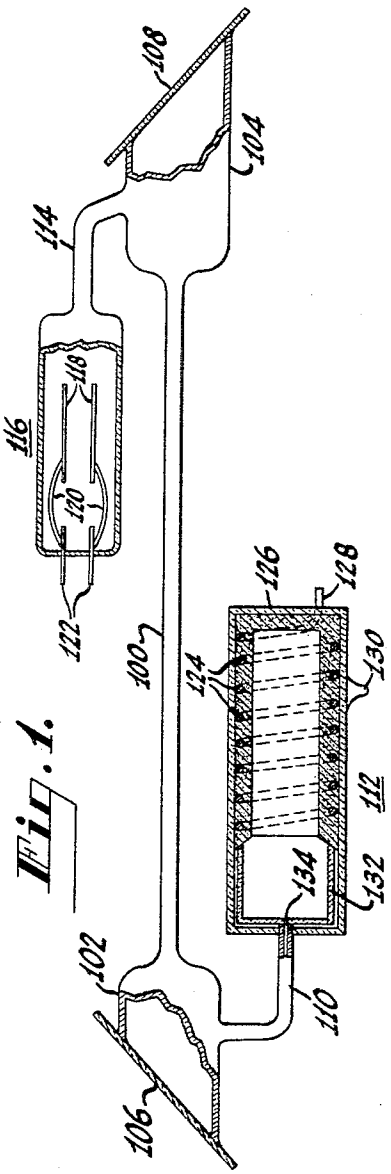


Fig. 1.

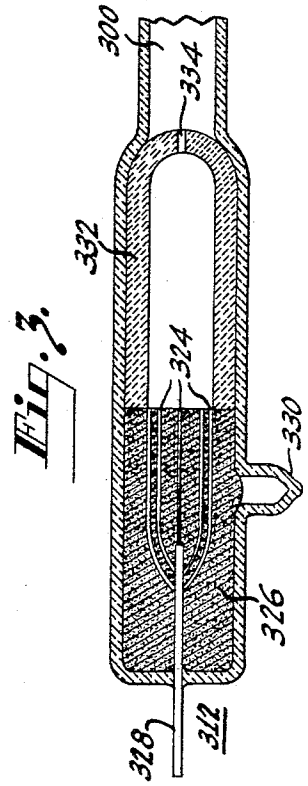


Fig. 3.

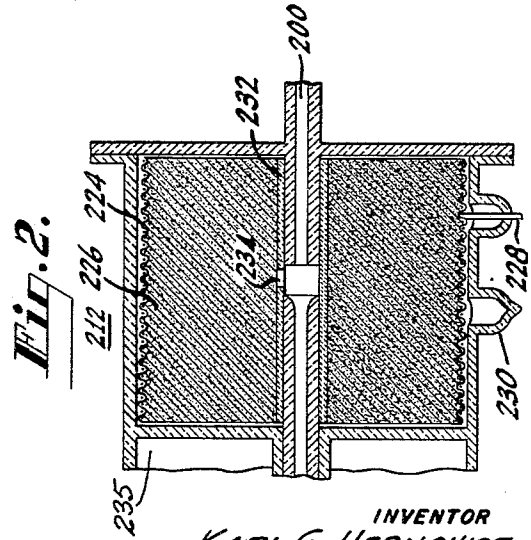


Fig. 2.

INVENTOR
KARL G. HERNQVIST

BY Edward J. Norton
ATTORNEY

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# SPUTTER RESISTIVE COLD CATHODE FOR LOW PRESSURE GAS DISCHARGE DEVICE

Karl G. Hernqvist, Princeton, N.J., assignor to RCA Corporation, a corporation of Delaware

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U.S. Cl. 313—211 11 Claims

## ABSTRACT OF THE DISCLOSURE

There is disclosed a cold cathode having an extremely long life which is particularly adapted for use in a gas discharge device, such as a gas laser, in which the gas pressure is no greater than ten torrs. The cold cathode comprises a porous layer of a normally non-emissive sputter resistant insulator, such as alumina, having an electrode embedded therein and a small amount of introduced alkali metal which is adsorbed by the surface of the insulator layer. The cold cathode is located in the terminating region of the discharge device enclosure to take advantage of the cataphoresis effect.

This invention relates to gas discharge devices and, more particularly, to an improved cold cathode for a low pressure gas discharge device, such as a gas laser, which by being sputter resistive provides a very long life for such a low pressure gas discharge device.

The use of cold cathodes for gas discharge devices, such as the familiar neon tube, which operate at gas pressures of ten torrs or more is old in the art. These cold cathodes usually comprise mainly an alkali earth compound, such as barium oxide or calcium oxide. In some cases a trace of an alkali metal is present for the purpose of lowering the work function of electron emission from the cathode. At gas pressures of ten torrs or more the amount of sputtering which takes place from such an alkali earth cold cathode is relatively small and such a cold cathode will operate satisfactorily for an extended period of time.

A gas laser, as known in the art, consists of means for discharging a suitable gas, such as carbon dioxide, a noble gas, or a mixture of noble gases, at suitable pressure within an optical resonant cavity. The gas pressure suitable for gas lasers, depending upon the particular gas being utilized, ranges from a few tenths of a torr to several torrs. In any case, the suitable gas pressure for gas lasers is below ten torrs, the minimum gas pressure normally employed in conventional gas discharge devices utilizing cold cathodes.

At low pressures (pressures below ten torrs) the mean free path of gas ions becomes quite large resulting in the gas ions which bombard the cold cathode having much higher velocities and kinetic energies than is the case where the gas pressure is relatively high (ten torrs or more).

It has been found that when conventional cold cathodes composed essentially of alkali earth compounds are utilized in low pressure (below ten torrs) gas discharge devices, such as a gas laser, the large kinetic energy of the bombarding gas ions causes excessive sputtering of the cold cathode to take place. This results in such a cold cathode when utilized in a low pressure gas discharge device having a very short life, such as one-half hour, for instance.

It is therefore an object of the present invention to provide an improved cold cathode for a gas discharge device operating at a gas pressure below ten torrs which has a very long life time.



It is a more specific object of the present invention to provide a cold cathode which is substantially resistant to sputtering when employed in a gas discharge tube having a gas pressure below ten torrs.

Briefly, in accordance with the present invention, the cathode electrode is embedded in a porous mass of any given substantially sputter resistant and normally non-emissive insulator which is chemically inert to a given alkali metal and such given alkali metal is made present to this mass of porous insulator so that a substantial portion of the surface of the mass is normally covered by some adsorbed given alkali metal. In addition, the cold cathode is inserted within a terminating region of the gas discharge enclosure which is connected to the remaining region of the gas discharge enclosure solely through constricting means comprising a small opening. The size of the opening is sufficiently small to result in the temperature at the opening during the discharge of gas therethrough being maintained high enough to substantially prevent any of the surface of that portion of the enclosure defining the opening from being covered by the given alkali metal.

The normally non-emissive insulator can be made into an effective sputter resistive cathode by the presence of adsorbed alkali metal. This is true because the alkali metal has a low electron emission work function; the adsorbed alkali metal at least to a certain extent is located within the pores of the mass of insulator, and, most important, the region of the insulator surface under the influence of each particle of adsorbed alkali metal acts as a conducting surface. If contiguous regions which are conductive are in overlapping relationship, which is the case when there is sufficient adsorbed alkali metal, an effective conductor is formed between the embedded electrode and the outer surface of the insulator mass.

Another feature of the present invention is that by locating the cathode in a terminating region of the enclosure, any deactivation of the cathode due to a loss of adsorbed alkali metal of the surface thereof during operation is continuously replaced by the process of cataphoresis. Also, loss of alkali metal caused by unwanted overheating of the cathode is temporary. More particularly, most of the alkali metal will return to the large effective surface of the cathode after it has cooled down. This is because the alkali metal adheres more strongly to the empty insulator surface than to itself, thus preventing droplets to remain at other parts of the tube. Therefore, damage to the cathode by overheating is self-healing, so that after a recuperation period of about an hour, normal operation may be resumed.

These and other objects, features and advantages of the present invention will become more apparent from the following detailed description taken together with the accompanying drawing in which:

FIG. 1 illustrates an embodiment of a gas discharge laser incorporating one embodiment of the improved cold cathode of the present invention;

FIG. 2 illustrates another embodiment of the improved cold cathode of the present invention; and

FIG. 3 illustrates still another embodiment of the improved cold cathode of the present invention.

Referring to FIG. 1, there is shown an embodiment of the present invention which is particularly suitable for use as the gas discharge tube in a gas laser. In particular, the discharge tube comprises tube **100**, which has a diameter of a few millimeters, coupled at one end to first enlarged region **102** and coupled at the other end to second enlarged region **104**. First enlarged region **102** is attached to optical window **106** cut at Brewster's angle with respect to the axis of tube **100**. Similarly, second enlarged region

104 is attached to optical window 108 also cut at Brewster's angle with respect to the axis of tube 100.

Coupled to first enlarged region 102 by coupling tube 110 is cold cathode 112. Coupled to the second enlarged region 104 by a coupling tube 114 is anode 116. As shown, anode 116 comprises electrode 118 which is electrically connected to the outside of the gas discharge enclosure by conductors 120 and 122.

Cold cathode 112 comprises a helical electrode 124, which may be made of tungsten, for instance, embedded in a layer of porous insulator 126, such as alumina ($Al_2O_3$) composed of a plurality of particles each of which particles may have the size of the order of five microns which as shown is attached to the side wall and distal end of the portion of the gas discharge enclosure forming cold cathode 112. Conductor 128 attached to the end of helical electrode 124 provides electrical connection of cold cathode 112 to the outside of the gas discharge enclosure. A small amount of an alkali metal, such as potassium is introduced into cathode 112 from a reservoir through a tube 130 which is then sealed off as shown. A ceramic insert 132, located as shown in FIG. 1, is provided with a small opening 134 which having a diameter in the order of one hundred to one hundred fifty mils provides the sole connection between coupling tube 110 and cold cathode 112, so as to form a constricting means. The entire gas discharge laser tube is filled with discharge gas, such as a mixture of helium and neon, for instance, at a gas pressure of considerably less than ten torr.

When conductors 122 are connected to a suitable point of positive potential (not shown) and conductor 128 is connected to a suitable point of negative potential (not shown) a gas discharge will take place from the surface of layer 126, through opening 134, coupling tube 110, first enlarged region 102, tube 100, second enlarged region 104, coupling tube 114, to electrode 118 of anode 116. This will result in the production of light within tube 100. If, as known in the laser art, the gas discharge laser tube is placed within an optical resonant cavity comprising a first and second parallel mirror surfaces (not shown) the first of which is outside of and in cooperative relationship with the light passing through window 106 and the second of which is outside of and in cooperative relationship with the light passing through window 108, lasing action will occur and coherent light will be generated.

It has been found that the operation of cold cathode 112 depends upon a certain amount of the alkali metal inserted inside the enclosure of the gas discharge laser tube being adsorbed by porous layer 126 of alumina, which has a high affinity therefor. Although not all of the surface of porous layer 126 is covered by adsorbed alkali metal, still some of the alkali metal is adsorbed within the pores of layer 126. Further, it has been found that the single outer shell electron of each adsorbed alkali metal atom spends a portion of its time within the surrounding surface molecules of insulator within its immediate vicinity. This results in a small region of the surface of insulator layer 126 in the vicinity of and under the influence of each adsorbed alkali metal atom effectively acting as a conductor, rather than as an insulator. Therefore, if, as is the case, there are sufficient number of adsorbed atoms of alkali metal to cause the respective regions under the influence of each of these adsorbed atoms to overlap, the entire surface of the insulator will act as a conductor. Since the insulator is porous, the effective surface thereof, to which alkali metal atoms are adsorbed, includes the tortuous microscopic paths through the myriads of pores in insulator layer 126. Thus a conductive path electrically connects embedded electrode 124 to the gas ions impinging on layer 126 of cold cathode 112. However, since layer 126 is composed of a sputter resistive insulator, such as alumina, negligible sputtering of this cold cathode material takes place during the operation of the gas discharge laser tube.

For example, it was found in practice that the cold cathode of the present invention, when employed in a gas discharge laser tube, had not deteriorated by sputtering or otherwise after two thousand hours of continuous operation of the gas discharge laser tube. The particular gas discharge laser tube which has been so operated had a quartz tube 100 having a three millimeter bore diameter and an effective length of 75 centimeters. This gas discharge laser tube was filled with a mixture of helium and neon gas and the alkali metal activator for the cold cathode was potassium.

Another feature of the present invention, as mentioned earlier, is that although cold cathode 112 becomes deactivated when operated considerably beyond its normal limits to overheat badly, causing an excessive amount of alkali metal to evaporate and settle on the colder envelope surface, this deactivation is only temporary. This is true because the alkali metal which has settled on the envelope eventually evaporates and most of it will end up condensing on alumina layer 126 which has a greater affinity for alumina than any other part of the gas discharge laser tube. Thus any damage to cold cathode 112 is "self-healing" and after a recuperation period of perhaps an hour, normal operation may be resumed.

Also, any alkali metal lost from the cathode region during operation due to heating and sputtering effects is continuously replaced due to the effect of cataphoresis. The cataphoresis effect comes about because the alkali metal atoms are easily ionized in the discharge and due to their positive charge drawn back to the negative cathode.

For cataphoresis to be effective it is necessary that cold cathode 112 be located in a terminating region of the gas discharge laser tube. The term "terminating region," as used herein, means that there is no other region of the enclosure coupled to the terminating region except that in which anode 118 is incorporated and through which the gas discharge takes place. In other words, in FIG. 1, if there were another additional portion of the gas discharge laser tube enclosure directly to the right of cold cathode 112 (into which gas could diffuse but in which no discharge would take place), which is not the case, cold cathode 112 would not be located in a terminating region of the enclosure. However, as is the actual case, where cold cathode 112 is coupled to the remaining region of the enclosure solely by coupling tube 110, cold cathode 112 is located within a terminating region of the enclosure.

FIGS. 2 and 3 show alternative forms which the cold cathode of the present invention may take.

In FIG. 2, cold cathode 212 incorporates tungsten mesh electrode 224 which is embedded in porous alumina layer 226 which is attached to the walls of that portion of the enclosure of the gas discharge laser tube defining the region of cold cathode 212. Connecting electrode 224 to the exterior is conductor 228. In FIG 2, discharge tube 200, which replaces discharge tube 100 in FIG. 1, is coaxially located as shown with respect to cold cathode 212 and is coupled thereto solely by small opening 234 in cylindrical ceramic insert 232. The right end of tube 200 is terminated in a Brewster angle window (not shown) and the left end of tube 200, which is terminated in another Brewster angle window (not shown), is coupled to region 235 in which is located an anode (not shown). Further, the desired alkali metal is inserted into cold cathode 212 from a reservoir through opening 230 prior to the sealing thereof.

In FIG. 3, cold cathode 312 utilizes electrodes 324 consisting of a plurality of tungsten wires embedded in a mass of alumina 326. As shown each of the plurality of embedded tungsten wires has one end thereof, which may have a diameter of ten mils, directly exposed to the gas within the gas discharge laser tube. The other end of the plurality of tungsten wires, as shown, are connected to conductor 328 which leads to the outside. Cold cathode 312 is coupled to the remainder of the gas discharge tube

solely by small opening **334** in ceramic insert **332**. The desired alkali metal is inserted into cold cathode **312** from a reservoir through opening **330** prior to the sealing thereof. The cold cathode embodiment shown in FIG. 3 is particularly useful for use in pulsed lasers, such as an argon pulse laser, where the exposed ends of electrodes **324** permit very high peak discharge currents (in the order of 100 amperes) during each pulse.

Although only certain preferred embodiments of the present invention have been described in detail herein, it is not intended that the invention be restricted thereto, but that it be limited only by the true spirit and scope of the appended claims.

What is claimed is:

**1.** In a gas discharge device comprising an enclosure having a gas capable of electric discharge contained therein, a cathode and an anode in spaced relationship with respect to each other positioned within said enclosure, first means for electrically connecting said cathode to one point outside of said enclosure, and second means for electrically connecting said anode to another point outside of said enclosure; the improvement wherein said enclosure incorporates constricting means for dividing said enclosure into a terminating region and a remaining region which regions are coupled to each other solely by a small opening of a given area, said anode being located wholly within said remaining region and said cathode being located wholly within said terminating region, wherein said cathode comprises a porous mass of a given substantially sputter resistant insulator located within said terminating region, said given insulator being chemically substantially inert to the presence of a given alkali metal, said mass having an embedded electrode distributed therewithin which electrode is in contact with said first means, and said given alkali metal being present within said terminating region, whereby at least a substantial portion of the surface of said mass is normally covered by adsorbed given alkali metal, and wherein the size of said given area is sufficiently small to result in the temperature at said opening during the discharge of said gas between said cathode and said anode through said opening being maintained high enough to substantially prevent any of the surface of that portion of said enclosure defining said opening from being covered by said given alkali metal.



**2.** The device defined in claim **1**, wherein said given insulator is alumina.

**3.** The device defined in claim **1**, wherein said mass is in the form of a layer in contact with the inner wall surface of that portion of said enclosure defining said terminating region.

**4.** The device defined in claim **1**, wherein said embedded electrode comprises at least one emerged portion which is exposed to the gas within said terminating region.

**5.** The device defined in claim **1**, wherein said embedded electrode comprises a plurality of spaced wires each of which has solely one end thereof emerging from said mass and exposed to the gas within said terminating region.

**6.** The device defined in claim **5**, wherein each of said wires has a diameter in the order of ten mils.

**7.** The device defined in claim **1**, wherein said constricting means comprises a ceramic insert in said enclosure.

**8.** The device defined in claim **7**, wherein said small opening comprises a hole in said ceramic insert having a diameter in the order of one hundred to one hundred fifty mils.

**9.** The device defined in claim **1**, wherein said mass is composed of a plurality of particles each of which particles has a size in the order of five microns.

**10.** The device defined in claim **1**, wherein the pressure of the gas within said enclosure is less than ten torrs.

**11.** The device defined in claim **1**, wherein said gas discharge device comprises a gas laser.

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JAMES W. LAWRENCE, Primary Examiner

R. F. HOSSFELD, Assistant Examiner

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