March 29, 1966 J. E. WHITE 3,243,632

THERMIONIC ARC DISCHARGE CATHODE GLOW LAMP

Filed Feb. 15, 1962

Fig. 1.

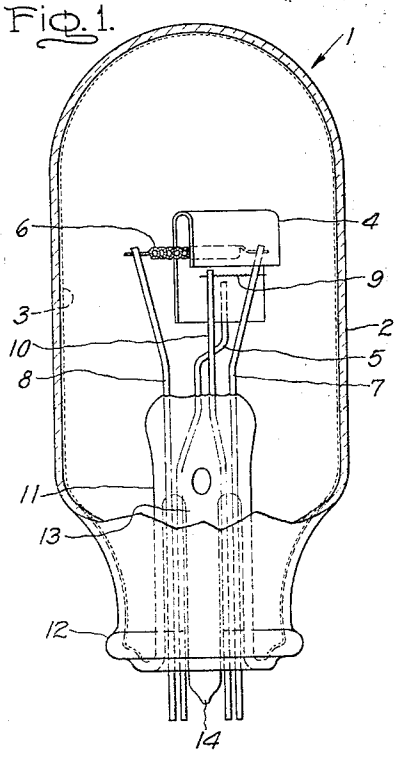


Fig. 2.

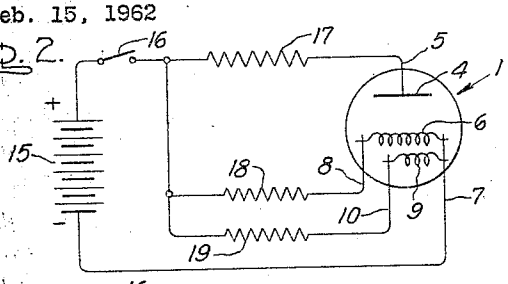


Fig. 3.

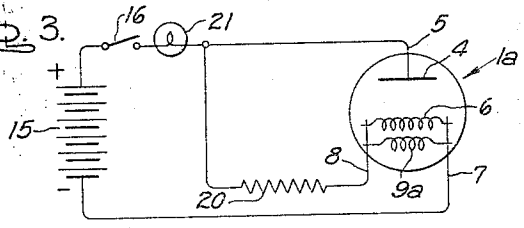


Fig. 4.

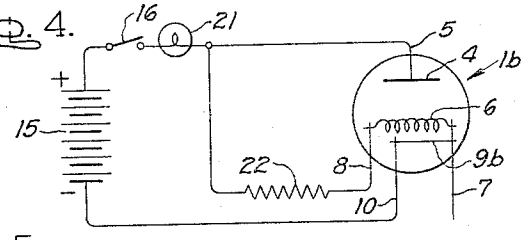


Fig. 5.

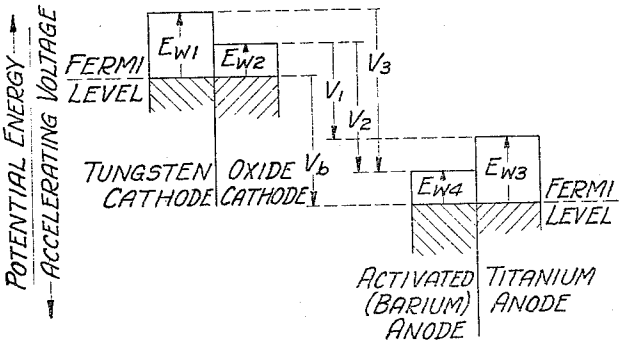


Fig. 6.

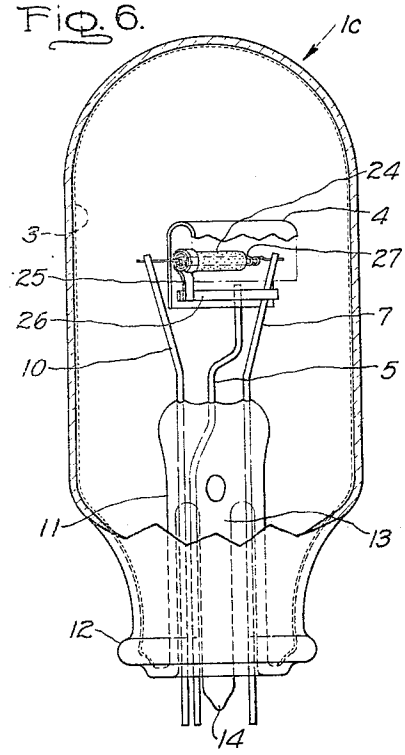
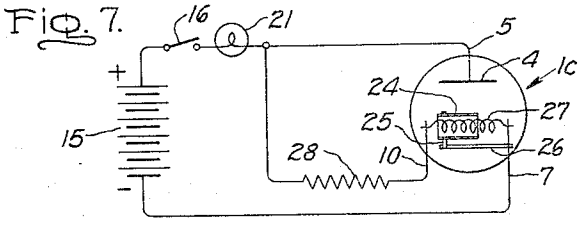


Fig. 7.



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3,243,632

THERMIONIC ARC DISCHARGE CATHODE GLOW LAMP

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12 Claims. (Cl. 313—213)

This invention relates generally to gaseous electric discharge devices, and more particularly to low voltage thermionic arc discharge lamps of the cathodic glow type. Such lamps generally operate at low voltages not much higher than the minimum voltage required to achieve ionization in the discharge medium.

Examples of the type of discharge lamp with which my invention is most useful are the lamps designated commercially RP–12 and 2W–T6. These lamps are miniature single-ended fluorescent lamps utilizing a thermionic arc in mercury vapor to produce 2537 A. ultraviolet radiation which excites a longer wavelength ultraviolet emitting phosphor coated on the envelope walls. One of its fields of application is in aircraft or vehicle instrument panel lighting wherein the instrument dials or indicia are coated with a fluorescent material which produces visible light upon irradiation by the long wavelength ultraviolet or so-called black light from the lamp.

In order to make such lamps practical and economically attractive for dashboard and instrument lighting in automobiles or vehicles using the now common 12-volt battery system, it is necessary that the lamps start reliably at a voltage as low as 11.5 volts. Also starting must be achieved without the use of special circuits such as inductive kick devices which would make the cost of the system unattractive. In practice, this means that the lamp must start upon mere application of the source or battery voltage through the circuit which limits or regulates the discharge current.

The general object of the invention is to provide improvements for lowering the starting voltage of low voltage thermionic arc discharge devices.

A specific object of the invention is to provide a thermionic arc discharge lamp of the cathodic glow type which will start reliably upon mere application of a D.-C. battery voltage of 11.5 volts.

Other objects of the invention are to provide optimized structures and operating circuits in respect of minimum ignition voltage and capacity to withstand overvoltage for thermionic arc discharge lamps of the cathodic glow type.

I have determined that in a relatively conservative gaseous discharge system where the ignition voltage approaches the lowest possible value, an arc is easier to ignite, that is it requires the application of less voltage, when a high work function cathode is used to provide initial ionization, than when a low work function cathode is used. In a thermionic arc low voltage discharge lamp embodying the invention, use is made of this discovery to achieve a lower ignition voltage by providing an auxiliary starting cathode of high work function to assist the main cathode of low work function in starting the arc.

In a preferred embodiment, the auxiliary cathode may consist of bare tungsten wire of coiled or straight wire configuration, while the main cathode conventionally may consist of a tungsten filament coated with an activating material such as alkaline earth metal oxides. Such an arrangement provides an advantage in ignition voltage equal substantially to the contact potential difference between the high work function auxiliary cathode and the low work function main or activated cathode. In

other words, other conditions remaining unchanged, the ignition voltage required to be applied is reduced by the contact potential difference between the high work function auxiliary cathode and the low work function main cathode. In actual practice, the reduction in ignition voltage is in the range of 2 to 2.5 volts.

In another preferred embodiment which is optimized for minimum current drain and capacity to withstand overvoltage in addition to minimum ignition voltage, an activated sleeve type cathode is used for the main cathode and the unactivated tungsten heater therefor is used as the auxiliary high work function cathode. Suitably the main cathode may take the form of a thin-walled cylinder having an external coating of activating material and an internal coating of insulating material. A bare tungsten filament or coil extends through the cylinder and serves as a heat source therefor; a portion of the coil projects beyond the end of the cylinder and operates as a high work function auxiliary cathode to provide high potential energy electrons for initiating the discharge.

For further objects and advantages and for a better understanding of the invention, attention is now directed to the following description and accompanying drawing illustrating a preferred embodiment. The features believed to be novel will be more particularly pointed out in the appended claims.

In the drawings wherein like reference numerals denote corresponding parts throughout the several sections:

FIG. 1 is a side elevation view, partly sectioned, of a miniature single-ended fluorescent lamp embodying the invention.

FIGS. 2 to 4 are schematic diagrams showing variations in main and auxiliary cathode interconnections within the lamp and operating circuits suitable therefor.

FIG. 5 is an energy level diagram showing the work functions and potentials in the lamp.

FIG. 6 is a side elevation view, partly sectioned, of a miniature single-ended fluorescent lamp embodying the invention and optimized for minimum ignition voltage along with low battery drain and capacity to withstand overvoltage.

FIG. 7 is a schematic diagram of a preferred operating circuit for the lamp of FIG. 6.

Referring to FIG. 1, the illustrated lamp **1** corresponds to the type designated commercially 2W/T6 having a nominal rating of 2 watts at an operating voltage of 11.5 volts. Except for the feature of the auxiliary cathode to be described, the lamp is constructed substantially as described and claimed in Patent 2,832,912, Lake, Electric Discharge Device, April 29, 1958. The envelope **2** of the lamp is generally tubular with a rounded end; typically it has a sealing length of 1⅝ inches and a diameter of ¾ inch. The lamp contains an ionizable medium consisting of a rare gas and a vaporizable metal, suitably argon at a filling pressure of 3.5 millimeters of mercury for a buffer gas, and a small quantity of mercury providing a pressure of mercury vapor determined by the operating temperature of the lamp. The envelope is coated internally with a phosphor **3** which fluoresces in the long ultraviolet region, for instance a cerium activated calcium phosphate or an aluminum silicate. Alternatively if a source of short wave ultraviolet radiation is desired, the phosphor coating is omitted and a vitreous material which transmits the desired ultraviolet is used for the envelope.

The lamp is provided with an anode **4** mounted on an inlead **5**, a main cathode **6** supported across inleads **7**, **8** and an auxiliary cathode **9** supported across inlead **7** which is common to the main cathode, and another inlead **10**. The inleads extend through a conventional stem **11** sealed peripherally at **12** to the bulb and including

an exhaust tube 13 which is tipped off at 14 after evacuation and filling of the lamp. The anode 4 is preferably a strip of titanium metal bent to a U-shape, inverted and with one leg extended downwardly and surrounding the main cathode 6. The main cathode is a triple-coiled tungsten filament of a kind common in tubular elongated fluorescent lamps. It is coated with electron-emissive material of low-work function such as alkaline earth oxides, for instance a triple mixture of barium, strontium and calcium oxides. Typically, the main cathode operates at a dull red heat and supports a discharge current of 200 milliamperes. The auxiliary cathode 9 may consist of a coil of bare tungsten wire or alternatively it may be a length of straight tungsten wire; it operates at white heat to support a discharge current of a few milliamperes at most. In a typical lamp, the U-shaped portion of the anode may be bent around a diameter of 3 to 4 millimeters, the main cathode coil may have a diameter of 1 millimeter, and the auxiliary cathode may be a straight length of tungsten wire 1.3 mils in diameter and about 5 milliameters long, located about 1.5 millimeter below and parallel to the main cathode coil.

A suitable circuit for energizing the lamp from a low voltage D.C. supply is illustrated schematically in FIG. 2. The battery 15, a 12-volt storage battery, may have its terminal voltage varying from a high of 13.5 volts to a low of 11.5 volts, depending upon the condition of charge. The negative pole of the battery is connected to inlead 7 which forms the common junction of main cathode 6 and auxiliary cathode 9. By closing switch 16, the positive pole of the battery is connected through a current limiting resistor 17 to the anode 4; at the same time a circuit is completed to the positive side of the battery through resistor 18 for main cathode 6, and through resistor 19 for auxiliary cathode 9. Resistors 18 and 19 limit the current through the cathodes and, being interposed between the positive side of the source and the cathodes, do not diminish the voltage effective between the anode and the most negative points in the cathodes to start and maintain the arc discharge.

The effectiveness of the auxiliary high-work function cathode in accordance with the invention for reducing ignition voltage will be apparent upon considering the results achieved consequent upon the processing and various modes of operation in the experiments to be described. In order to obtain a pure titanium surface at the anode, induction heat may be used to thoroughly clean the anode. This gives a reaction with products that may have been deposited on its surface as a result of cathode seasoning, the gaseous components becoming dissolved into the volume of the titanium to leave a surface of pure titanium metal. For testing for arc ignition voltage, the lamp was mounted vertically with its seal pressed against a padded theremocouple in a transite base; the latter served to cool slightly the region of the lamp envelope next to the thermocouple and to hold condensed mercury there in order to have a constant mercury vapor pressure. A cylindrical Pyrex-walled heater was used to keep condensate off the walls of the lamp, make the base temperature controllable, and permit observation of the discharge. A starting and operating circuit similar to that illustrated in FIG. 2 was used but including provision for varying the supply voltage, for regulating the heating current through the cathodes, or for open circuiting either cathode heating circuit.

For the first experiment, the cathode was thoroughly cleaned by induction heat. Then, with the auxiliary cathode cold, the main cathode at normal heat of approximately 900° C., and the condensed mercury at room temperature, arc ignition required the application of at least 14.8 volts to the anode relative to the negative end of the cathode. In other words, a minimum battery voltage of 14.8 volts is required to start the lamp.

For the second experiment, the anode was activated by a layer of barium or barium oxide. Activation is achieved by condensing a light deposite of activating material vaporized from the cathode onto the anode; the deposit is probably a mono-molecular layer of barium and it is readily obtained by passing an excessive current through the main cathode to overheat it for a brief interval of time. When the arc ignition voltage is now again measured (with the auxiliary cathode still cold), it is found to have dropped to 12.7 volts. The conditions of this experiment are typical for prior art lamps and the ignition voltage of 12.7 volts is likewise typical for prior art lamps.

If the last experiment is now repeated with the auxiliary tungsten cathode heated to white heat, the anode still being activated and the main cathode being at normal dull red heat, the arc ignition voltage is found to be reduced to 10.4 volts. Thus, other conditions being equal, the provision of an auxiliary tungsten cathode in accordance with the invention results in a lowering of the arc ignition voltage from 12.7 to 10.4 volts. This a reduction of 2.3 volts, substantially 20%, and it makes the lamp practical for operation on a 12 volt storage battery.

The foregoing results may be explained on the basis of the contact potential differences resulting from the differences between the work functions of the various electrodes. When two different metals are joined together, electrons will flow across the boundary from the lower work function metal to the higher work function metal until the latter has acquired a negative charge such that net electron flow ceases. The equilibrium condition of equal electron flow across the boundary in each direction is attained when the Fermi energies of the two metals are located at the same height on the energy level diagram. This situation is depicted in FIG. 5, on the left side for the case of the tungsten cathode having an oxide cathode surface in contact therewith, and on the right side for the case of the titanium anode having an activated (barium) anode surface in contact therewith. The Fermi energies at the cathodes are shown at the same level; likewise the Fermi energies at the anodes are shown at the same level; the Fermi levels as between cathode and anode are at a voltage difference V_b which is the applied battery voltage. It follows from the condition of common Fermi energy levels that the contact difference of potential between two metals is equal to the difference between their work functions, the metal with the smaller work function becoming positively charged and the metal with the higher work function becoming negatively charged.

In the first experiment described earlier, the arc ignition voltage for a pure titanium anode and the oxide coated main cathode at normal heat is 14.8 volts. The voltage effective to accelerate an electron from a point just outside the surface of the oxide cathode to a point just outside the surface of the titanium anode is represented in FIG. 5 by V_1. It will be observed that

$$V_1 = V_b + E_{w2} - E_{w3}$$

wherein

E_{w2}=work function of oxide cathode, and

E_{w3}=work function of titanium anode.

The applied voltage is here opposed by the contact potential difference equal to the difference between the work functions of titanium anode and oxide cathode. For a titanium anode and an oxide cathode, published values of the work functions would indicate a contact potential difference of approximately 2.5 volts. The contact potential difference is in a direction opposing the voltage applied to start the lamp and therefore the source or battery voltage must be increased an equivalent amount in order to achieve ignition.

In the second experiment, the presence of an activating layer of barium metal or barium oxide on the titanium anode reduces the ignition voltage to 12.7 volts. The as-

celerating voltage in this case is represented in FIG. 5 by V_2. It will be observed that

$$V_2=V_b+E_{W2}-E_{W4}$$

wherein E_{W4}=work function of (barium) activated titanium anode.

The shift in contact potential responsible for this voltage reduction must be equal to the shift in anode work function which is thus 2.1 volts. Since the work function of titanium metal is 4.1 volts, that of the "activated" anode is 2.1 volts less, namely 2.0 volts. With anode and cathode work functions about the same, the contact potential differences approaches zero and it will be observed in FIG. 5 that V_2 is approximately equal to V_b; in other words the applied source voltage is neither opposed nor aided by the contact potentials. This is the condition which has been prevalent in prior art lamps.

In the third experiment, wherein the anode was activated and both the auxiliary tungsten cathode and the main cathode were heated, the arc ignition voltage was reduced to 10.4 volts. The voltage effective under these conditions to accelerate those electrons which are emitted by the auxiliary unactivated tungsten electrode is represented in FIG. 5 by V_3. It will be observed that

$$V_3=V_b+E_{W1}-E_{W4}$$

wherein E_{W1}=work function of tungsten cathode.

The work function of tungsten is approximately 4.5 volts and the further reduction of 2.3 volts in ignition voltage is approximately the difference in work functions between the tungsten cathode and the oxide cathode surface.

The auxiliary tungsten cathode performs the function of emitting only a relatively small proportion of electrons having higher potential energies than the principal volume of electrons emitted by the main oxide coated cathode. These higher potential energy electrons are accelerated to higher velocities and generate enough ions to partially neutralize the electron space charge at the main or oxide coated cathode. Neutralization of the electron space charge permits increased current flow from the main cathode resulting in ignition of the thermionic arc; current flow then occurs primarily from the main oxide coated cathode. Thus in the lamp which has been specifically described, the main cathode is rated to emit several times this value of current. However the auxiliary tungsten cathode need only emit currents of a fraction of a milliampere to a few milliamperes at most, for instance ½ milliampere for the specific lamp described.

In order to achieve the lowest possible ignition voltage for the thermionic arc, the auxiliary tungsten electrode should be connected to the negative terminal of the battery. By so doing, the relatively high potential energy electrons emitted by the tungsten auxiliary cathode are subjected to the maximum accelerating potential available. It is necessary of course that the heating current for each cathode raise its temperature to a range of effective electron emission, for instance 800 to 1200° C., suitably 900° C. in the case of the main oxide coated cathode, and 1800° C. to 2800° C., suitably 2500° C. in the case of the tungsten auxiliary cathode. In the circuit of FIG. 2, the required heating currents are achieved by providing separate current limiting resistors for each cathode, **18** for the main cathode and **19** for the auxiliary cathode.

By proportioning auxiliary cathode **9***a* in lamp **1***a* of FIG. 3 such that the desired heating current occurs under conditions of equal voltage or IR drop across the two cathodes, both cathodes may be connected in parallel across a single pair of inleads **7**, **8** as illustrated. In such case, a single resistor **20** may be used to limit the current through both cathodes simultaneously. It is also desirable to protect the filamentary cathodes from battery overvoltages such as may occur when the automotive generator is recharging the battery at a high rate

from a condition of low charge. In the circuit of FIG. 3, this is accomplished by providing a ballasting or current limiting impedance having a large positive temperature coefficient of resistance in the form of a tungsten filament lamp **21** in the anode circuit. The resistor **20** is connected between the cathodes **6**, **9***a* and the anode **4** so that the cathode heating current must flow through the ballast lamp **21**. When the switch is first closed and before the lamp has ignited, only the cathode heating current flows through the ballast lamp. Under these conditions, the ballast lamp is relatively cold and its filament resistance is low so that it causes minimum reduction in the voltage available for ignition; for the lamp which has been described, the voltage drop across lamp **21** prior to ignition may be as low as 0.35 volt. After ignition, a relatively constant voltage drop occurs across the arc discharge of the discharge lamp. Variations in battery voltage cause some variation in current through the discharge lamp and commensurate variations in voltage drop across ballast lamp **21** but little variation in voltage across the discharge lamp. As a result, the heating current through the cathodes decreases due to the voltage drop across the ballast lamp as soon as the discharge lamp ignites, and thereafter the filamentary cathodes are protected from overvoltage.

Instead of designing the two cathodes for equal voltage drop, they may be designed for equal current flow at the desired operating temperatures. The same current may then be caused to flow through the two filamentary cathodes in series and an appreciable reduction in battery drain may be effected thereby. In such case, the end of auxiliary electrode **9***b* in lamp **1***b* is connected to the negative side of the battery and the end of main electrode **6** is connected through current regulating resistor **22** to the anode so that the cathode heating current is caused to flow through ballast lamp **21**, as illustrated in FIG. 4. The common junction of the two cathodes has no external connection and assumes a potential, as regards its Fermi level, which is raised above the potential of the negative side of the battery by an amount equal to the voltage or IR drop across the auxiliary electrode. Since this voltage drop is in a direction to reduce the potential available to accelerate electrons from the main cathode towards the anode, it should preferably be kept as small as possible and accordingly, in such an arrangement, the auxiliary cathode may suitably consist of a relatively short straight piece of tungsten wire as illustrated.

FIG. 6 illustrates a preferred embodiment of the invention, being a lamp **1***c* wherein the cathode structures are optimized for lowest ignition voltage and minimum battery drain together with protection from battery overvoltage. In lamp **1** illustrated in FIG. 1, it is primarily the negative end of the main cathode which is effective in emitting electrons to support the arc discharge during normal operation. Nevertheless, energy must be supplied to heat the entire main cathode and also the auxiliary cathode, and this of course entails a current drain on the battery. The same comment applies to lamp **1***a* of FIG. 3. In lamp variant **1***b* illustrated schematically in FIG. 4, it is apparent that the voltage drop across the auxiliary cathode **9***b* reduces the effective voltage between main cathode and anode; the auxiliary cathode **9***b* must also be designed to support the entire discharge current without burning out. These several disadvantages or limitations are avoided by the cathode structure of lamp **1***c* illustrated in FIG. 6 which is otherwise similar to lamp **1** previously described.

Referring to FIG. 6, an equipotential main cathode is provided in the form of an open-ended cylinder or sleeve **24**. The sleeve is metal and desirably thin-walled in order to have a low thermal capacity and heat up rapidly. On the outside it is provided with an activating coating, suitably an electron emissive coating of alkaline earth oxides. On the inside, it is provided with an insulating

coating, suitably a coating of an aluminum oxide glaze. A convenient way to make the sleeve 24 is to wind a tight pitch coil or close helix of tungsten wire of appropriate size which is thereafter sintered to bind all the turns together. The surface corrugations in the tungsten sleeve so made help to bind the surface coatings thereto. The cathode sleeve 24 is connected to and supported by inlead 7 by means of a ring clamp 25 which encircles one end and a strap 26 spot welded thereto.

A bare tungsten wire coil 27 extends through sleeve 24 and is clamped at its ends to inleads 7 and 10. Coil 27 is insulated from cathode sleeve 24 by the insulating coating on its internal surface but serves as a heater therefor to raise its temperature to the range of electron emission, that is 800 to1200° C. At the same time, coil 27 serves as the high work function auxiliary cathode which, as previously described, reduces the ignition voltage by emitting a small percentage of high potential energy electrons. The effectiveness of coil 27 as an auxiliary cathode is enhanced by extending the portion thereof closest to inlead 7 beyond the end of sleeve 24 so as to emit its electrons in a more favorable electric field for producing ionization. Ring clamp 25 which supports the sleeve is attached to the sleeve at the end remote from the exposed turns of coil 27 to permit the end close thereto to heat up rapidly.

FIG. 7 illustrates schematically an operating circuit for deriving maximum benefit from the cathode structure of lamp 1c. The negative pole of the battery is connected to inlead 7 to which both main cathode sleeve 24 and the projecting portion of heater coil 27 are connected. This assures that the most negative potential available is applied to both main and auxiliary cathodes. Anode 4 is connected through ballast lamp 21 to the positive side of the battery. Resistor 28 is connected between inlead 10 and inlead 5 of anode 4 to regulate the cathode heating current through auxiliary cathode coil 27. This circuit configuration achieves minimum ignition voltage along with minimum current drain on the battery for a given discharge current. At the same time, the auxiliary cathode is protected against battery overvoltage inasmuch as the voltage applied across it and series resistor 28 during operating is stabilized by the relatively constant voltage drop across the thermionic arc discharge.

While certain specific embodiments of the invention have been illustrated and described, they are intended as illustrative and not as limitative of the invention. By applying the principles which have been explained, the necessary modifications for using the invention in lamps or discharge devices differing widely in shape, size and rating from those which have been considered herein will readily occur to those skilled in the art. The appended claims are intended to cover any such modifications coming 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 thermionic arc electric discharge lamp of the cathodic glow type having an operating voltage not much higher than its minimum ionization voltage comprising an envelope filled with an ionizable medium and having sealed therein an anode, a main thermionic filamentary cathode activated to have a relatively low work function for supporting the major part of the electron discharge current, an auxiliary thermionic filamentary cathode of relatively high work function non-activated metal, and inlead connections for supplying current to both cathodes to heat them to effective electron-emitting temperature and for applying a potential to the anode relative to the cathodes, said connections placing one end of said auxiliary cathode at the most negative potential in said lamp in order to provide a small proportion of relatively high speed electrons for reducing the ignition voltage.

2. A lamp as defined in claim 1 wherein the operating voltage is of the order of magnitude of the ionizing potential of mercury, the ionizable medium comprises an inert starting gas at a low pressure and a small quantity of mercury, the main filamentary cathode is activated with alkaline earth oxides, and the auxiliary filamentary cathode is unactivated tungsten wire.

3. A lamp as defined in claim 2 wherein the main filamentary cathode is proportioned to operate in the temperature range of 800 to 1200° C. for supporting the major part of the discharge current, and the auxiliary cathode is proportioned to operate in the temperature range of 1800 to 2800° C.

4. A lamp as defined in claim 3 wherein main and auxiliary cathodes are connected in parallel.

5. A lamp as defined in claim 3 wherein main and auxiliary cathodes are connected in series.

6. A thermionic arc electric discharge lamp of the cathodic glow type comprising an envelope filled with an ionizable medium and having sealed therein an anode, a main thermionic cathode comprising a metal sleeve activated to have a relatively low work function for supporting the major part of the electron discharge current, and an auxiliary thermionic filamentary cathode of relatively high work function non-activated metal, said auxiliary filamentary cathode extending through said sleeve to heat same, and inlead connections for supplying current to said auxiliary cathode in order to heat it and said sleeve to effective electron-emitting temperature and for applying a potential to the anode relative to the cathodes, said connections placing one end of said auxliary cathode at the most negative potential in said lamp in order to provide a small proportion of relatively high speed electrons for reducing the ignition voltage.

7. A thermionic arc electric discharge lamp of the cathodic glow type having an operating voltage of the order of magnitude of the ionizing potental of mercury comprising an envelope filled with an ionizable medium comprising an inert starting gas at a low pressure and a small quantity of mercury, and having sealed therein an anode, a main thermionic cathode comprising a thin-walled metal sleeve activated with alkaline earth oxides to have a relatively low work function for supporting the major part of the electron discharge current, and auxiliary thermionic filamentary cathode of unactivated tungsten wire having a relatively high work function, said auxiliary filamentary cathode extending through said sleeve to heat same, and inlead connections for supplying current to said auxiliary cathode in order to heat it and said sleeve to effective electron-emitting temperature and for applying a potential to the anode relative to the cathodes, said connections placing one end of said auxiliary cathode at the most negative potential in said lamp in order to provide a small proportion of relatively high-speed electrons for partially neutralizing the electron space charge at said main cathode whereby to reduce the ignition voltage.

8. A lamp as defined in claim 7 wherein said sleeve is connected to the end of said auxiliary cathode operable at the most negative potential in said lamp.

9. A thermionic arc electric discharge lamp of the cathodic glow type having an operating voltage of the order of magnitude of the ionizing potential of mercury comprising an envelope having an ionizable medium therein comprising an inert starting gas at a low pressure and a small quantity of mercury, and having sealed therein an activated anode, a main thermionic low work function cathode comprising a thin-walled tungsten sleeve having an external activating coating of alkaline earth oxides and operable in the temperature range of 800 to 1200° C. for supporting the major part of the electron discharge current and having an internal insulating coating, and an auxiliary thermionic filamentary high work function cathode comprising a coil of unactivated tungsten wire extending through said sleeve to heat same, and inlead connections for supplying current to said coil in order to heat it to the temperature range of 1800 to 2800° C. and for applying a potential to the anode relative to the cathodes

said connections placing one end of said coil at the most negative potential in the lamp in order to inject a small proportion of high-speed electrons for partially neutralizing the electron space charge at the main cathode whereby to reduce the ignition voltage, said coil serving simultaneously as a heater to heat said sleeve to said temperature range of 800 to 1200° C.

10. A lamp as defined in claim **9** wherein a portion of said tungsten wire coil projects beyond an end of said sleeve.

11. A lamp as defined in claim **9** wherein a portion of said tungsten wire coil projects beyond one end of said sleeve and said sleeve is supported from its other end in order to achieve more rapid heating of said one end.

12. A lamp as defined in claim **9** wherein said tungsten sleeve consists of a tight pitch helix of fine tungsten wire having its turns sintered together.

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