Oct. 24, 1961 J. J. MASON 3,005,930

ELECTRIC DISCHARGE APPARATUS

Filed Aug. 12, 1957

Fig. 1.

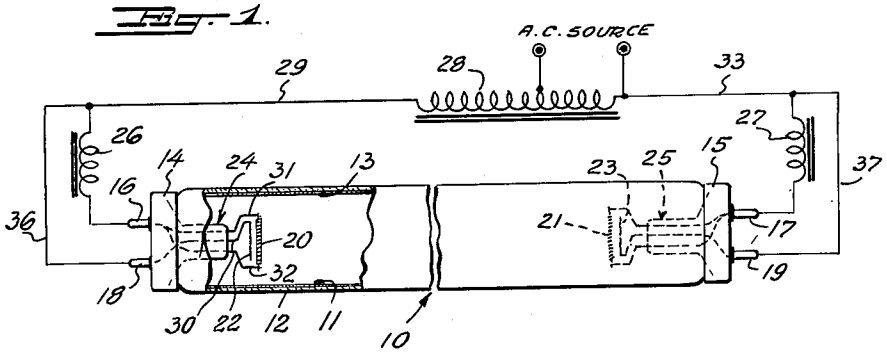


Fig. 2.

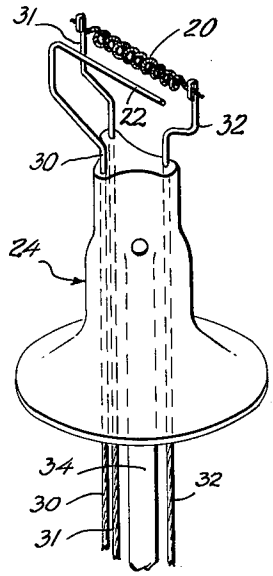


Fig. 3a.

a. MAIN DISCHARGE AND LINE CURRENT

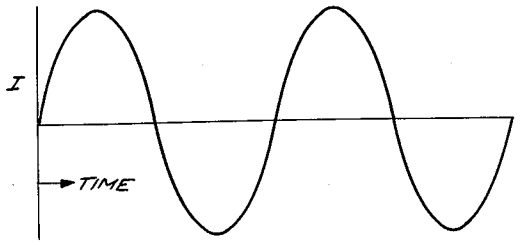


Fig. 3b.

b. CATHODE CURRENT

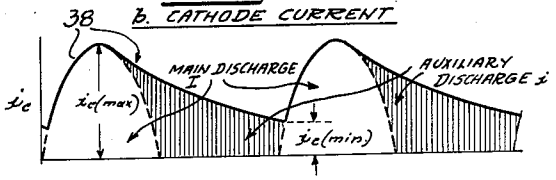


Fig. 3c.

c. ANODE CURRENT

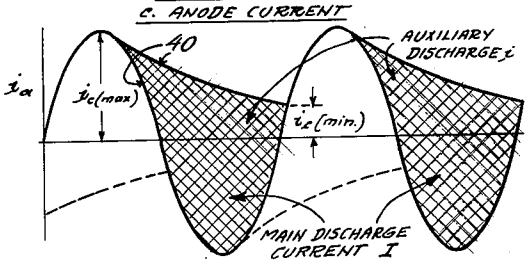
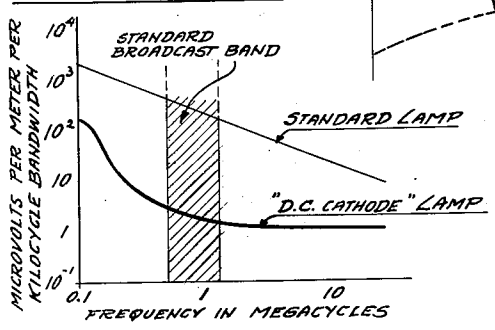


Fig. 4.

PEAK "RF" NOISE SPECTRUM



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ELECTRIC DISCHARGE APPARATUS

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This invention relates generally to electric discharge apparatus and, more particularly, to a fluorescent lamp system which may be operated from an alternating voltage source with a minimum amount of radio interference.

It is common knowledge that when an electric discharge device such as a fluorescent lamp is operated from an A.C. power source, high-frequency radiations are generated which, unless preventive measures are taken, are propagated by various means resulting in the production of the well-known "crackling" or "frying" noise in the audio output of any radio operated within range that renders intelligible radio reception difficult or impossible or generally interfering with the operation of equipment susceptible to such radiations, as for example sensitive electrical meters and the like. The generation of such undesirable electromagnetic radiations is a fault common to "hot-cathode" gaseous discharge devices of all types and manufactures, that is, those in which at least one of the elements supporting the discharge develops a cathode "hot-spot" during operation and becomes a thermionic emitter.

The problem is of particular significance in the fluorescent lamp industry by virtue of the widespread use of such lamps for general lighting purposes and the difficulty of suppressing or isolating the undesirable radiations once the lighting apparatus has been installed. The magnitude of the radio-frequency or so-called "RF" noise produced may vary widely between lamps of the same design and between alternate half cycles of operation of the same lamp. While the phenomenon as a whole is very complex and not as yet perfectly understood, it has been determined that the cathode is the primary source of such noise within the broadcast band and that the most pronounced components occur in the low current portions of each half cycle, that is, in the early and late portions of each half cycle of the cathode current. By virtue of their location on the generally sinusoidal waveform of the cathode current these components may be loosely termed "ignition" and "extinction" noise, by which terminology they will hereinafter be identified. It should be noted, however, that investigation has shown that the noise is a function of a critical range of low discharge current rather than the actual ignition or extinction of the discharge between each half cycle of the applied A.C. voltage so that the foregoing terminology should not be interpreted literally.

It has been theorized that the generation of "RF" noise by "hot-cathode" type gaseous discharges is due to transitions in the process of ionization within the region of the cathode fall voltage and a periodic disturbance of cathode equilibrium. Such cathode instability is believed to result from the inherent time delay between the cause and effect of ion generation within the cathode fall. Since the electron current from the cathode depends upon the positive ion current to it, under equilibrium conditions a cathode fall somewhat in excess of the ionization (or resonance) potential of the gas is required. The instantaneous cathode fall, however, depends upon the instantaneous ion concentration near the cathode and, in the absence of equilibrium, will rise or fall to regulate the positive ion supply. Since the ions are formed some distance away, the full effect upon the cathode of a change in ionization rate is not immediate. Over-regulation,

therefore, apparently occurs and oscillations of the cathode fall are produced whenever cathode equilibrium is disturbed resulting in the generation of radio-interference radiations. The periodic occurrence of such radiations in the rising and falling portions of each half cycle of cathode current is apparently caused by transitions in the process by which ions are created near the cathode as the cathode fall voltage passes through critical potentials of mercury vapor and argon. With each transition the efficiency of ion production changes, somewhat abruptly because of the space-charge-restricted electron energy distribution, thereby disturbing the cathode equilibrium and initiating the oscillatory process. Inasmuch as not all transitional values of discharge current can reasonably be satisfied by a continuous ionization process, oscillations of the cathode fall voltage and the generation of radio interference incident therewith will thus persist over certain critical ranges of current, even during D.C. operation of the lamp.

Accordingly, it has been theorized that radio interference will be reduced by avoiding insofar as is possible, the abrupt changes in ionization efficiency which normally occur during the transitions of the cathode fall within the A.C. half cycle. In the case of a fluorescent lamp of conventional design this requires that the cathode fall be maintained at its normal level above the excitation potental of argon.

Heretofore, attempts have been made to suppress radio interference of this character by properly positioning or shielding the lamp or radio to prevent the radiations emanating directly from the lamp or its supply line from reaching the aerial circuit of the radio. Line radiation and feedback were somewhat reduced by placing a capacitor-type filter in the line as close as possible to each lamp or fixture thereby confining the troublesome radiations to the lamp proper. These preventive measures were far from satisfactory not only because of their relative ineffectiveness but due to the expense and inconvenience involved and the drastic reduction in light output obtained from the lamp when the latter was shielded.

It is accordingly the general object of the present invention to provide an electric discharge apparatus which may be operated from an alternating voltage source without producing objectionable amounts of radio-interference.

A more specific object of the invention is the provision of a fluorescent type lighting system wherein the generation of undesirable radio-frequency radiations incident with the A.C. operation thereof are substantially eliminated.

Still another object of the present invention is the provision of a simple, convenient and inexpensive means for suppressing the radio-frequency noise incident with the A.C. operation of electric discharge devices having thermionic electrodes.

The foregoing objects and others which will become obvious to those skilled in the art are achieved by providing within the discharge device adjacent to each of the main electrodes an auxiliary electrode which is less electron-missive than the main electrode and adapted, in conjunction with an electrical-storage component in the energizing circuit, to produce an auxiliary discharge between the main and auxiliary electrodes at each end of the lamp when the polarity thereat is positive and thus draw current from the main electrodes during that portion of the cycle when they would ordinarily function as anodes, the latter function being performed by the auxiliary electrodes. Or, in other words, by operating the main electrodes as part of a "D.C." auxiliary circuit while the device as a whole operates A.C. so that each of the main electrodes continuously function as a cathode and has a current flow which is unidirectional in character

and maintained at a level greater than the "critical" value at which cathode instability and the "ignition" and "extinction" noise components of radio-interference occur.

A better understanding of the invention may be obtained by referring to the accompanying drawing wherein:

FIG. 1 is an elevational view of a fluorescent lamp and a schematic diagram of an A.C. energizing circuit therefor according to the present invention;

FIG. 2 is an enlarged view of an electrode mount utilized in the lamp shown in FIG. 1;

FIG. 3*a*, *b* and *c* are graphical representations of the main discharge or line current and the cathode and anode currents, respectively, of the lamp shown in FIG. 1 during the A.C. operation thereof according to the invention; and

FIG. 4 is a graphical comparison of the "RF" noise levels over a large range of frequencies, including the broadcast band, of a standard type lamp and a lamp fabricated and operated according to this invention.

While the invention may be utilized in conjunction with any A.C.-operated electric discharge device which produces radio interference, it is especially adapted for use with fluorescent type lighting systems and hence has been so illustrated and will be so described.

With specific reference now to the form of the invention illustrated in the drawing, in FIG. 1 there is shown a fluorescent lamp 10 which, briefly stated, comprises a tubular light-transmitting envelope 12 sealed at both ends by mounts 24 and 25 and containing an ionizable medium such as a droplet of mercury 11 and argon gas together with a quantity of phosphor distributed over its inner surface in the form of a coating 13. The mounts 24 and 25 each carry a main electrode 20 and 21 and an auxiliary electrode 22 and 23, respectively, which are sealed within the envelope 12 and connect with a series of contact pins 16, 17, 18 and 19 carried by base members 14 and 15 attached to the ends of said envelope. Inasmuch as both ends of the lamp 10 are identical as regards construction and operation, only the left-hand end of said lamp, as viewed in FIG. 1, has been illustrated in detail and will be hereinafter described.

The mount 24 as shown in FIG. 2 may be of the well-known glass stem construction wherein three lead wires 30, 31 and 32 are hermetically sealed through a press formed at the end of a flared section of glass tubing. In accordance with standard fluorescent lamp-making practice the sections of the leads 30, 31 and 32 which protrude from the press are preferably fabricated from nickel or other suitable material which will not readily combine with mercury. A tubulation 34 depends from the opposite end of the mount 24 to facilitate the evacuation of the envelope 12 after the ends have been sealed-off. The main electrode 20 is transversely connected to the end sections of the lead wires 31 and 32 which extend from the stem press whereas the corresponding section of the lead 30 may be bent in the shape of a hook having a straight end disposed adjacent to and in generally parallel relation with the main electrode 20 to thus form the auxiliary electrode 22. At least one of the main electrodes 20 and 21 is thermionic and may comprise a filamentary coil of refractory metal such as tungsten or the like impregnated with a suitable electron-emissive material such as the conventional alkaline earth compounds. The auxiliary electrodes 22 and 23, however, being formed from the lead wire or other suitable material are less electron-emissive than the main electrodes 20 and 21, which characteristic is advantageously utilized as will become evident as the description proceeds.

As shown in FIG. 1, the leads 31 and 32 are exteriorly connected to one of the contact pins 16 whereas the auxiliary electrode 22 is connected by means of the lead 30 to the other of the pins 18, similar junctures being made at the opposite end of the lamp 10 between the main electrode 21, auxiliary electrode 23 and pins 17 and 19. Operation of the lamp 10 is effected by connecting the pins 16 and 17 to an auto-transformer 28 through suitable conductors 29 and 33 which include electrical-storage elements such as inductances or chokes 26 and 27. This arrangement, minus the chokes 26 and 27, provides the well-known instant-start type energizing circuit wherein upon the application of an A.C. voltage to the primary of the transformer 28 an electrical potential of such magnitude is impressed across the main electrodes 20 and 21 that an arc is struck therebetween starting the lamp 10. The transformer 28 thereafter acts as a ballast and regulates the discharge in the well-known manner.

The auxiliary electrodes 22 and 23 are connected to the energizing circuit and the line side of the chokes 26 and 27 by means of conductors 36 and 37 which connect with the other contact pins 18 and 19, respectively. This arrangement thus provides an energizing circuit which includes the transformer 28, the chokes 26 and 27 and the main electrodes 20 and 21 and permits the lamp 10 to be A.C.-operated in the regular manner. In accordance with the invention a branch or auxiliary circuit is also provided by the foregoing arrangement which circuit includes in common with the aforementioned energizing circuit the chokes 26 and 27 and main electrodes 20 and 21, thereafter branching out to the auxiliary electrodes 22 and 23 and back to the line side of the chokes 26 and 27 and the energizing circuit by means of the conductors 36 and 37, respectively. It should be noted that in contrast to the usual prior art practice with respect to the use of auxiliary electrodes, the auxiliary electrodes 22 and 23 as herein employed are not intended to facilitate the initiation of the main discharge in any manner and in fact do not fulfill their intended purpose until the lamp 10 is put into operation, as will become evident as the description proceeds.

As shown in FIG. 3*a*, the line current I which flows through the energizing circuit and main discharge is generally sinusoidal in form as in the case of any normally A.C.-operated lamp. When the end of the lamp 10 to the left (as viewed in FIG. 1) is negative, the main electrode 20 functions as a cathode and supplies all the current I for the main discharge during that half cycle of operation, the current rising from zero to a peak and back to zero as indicated in FIG. 3*a*. According to the invention a part of the electrical energy supplied to the main electrode 20 during the rising-current portion of the cathode half cycle is stored in the choke 26 and, as the cathode current starts to decrease, is progressively released and utilized to initiate and sustain an auxiliary discharge between the main electrode 20 and its adjacent auxiliary electrode 22. The magnitude of the auxiliary current *i* generated by the choke 26 builds up slowly as the main discharge current I starts to drop off, reaches a maximum as the latter quickly drops to zero and then drops off exponentially during the half cycle and beginning of the next full cycle which follow. Hence, after the main discharge current I reaches a peak and begins to decrease the choke 26 initiates an auxiliary discharge between the main electrode 20 and the auxiliary electrode 22 causing an auxiliary discharge current *i* (FIG. 3*b*) to flow such that the cathode current i_c decays from a peak value i_c (max.) to a value i_c (min.) during the remainder of the cathode half cycle, the next half cycle and the leading portion of the succeeding full cycle. Consequently, the cathode current i_c instead of falling to zero, as indicated by the trailing dotted-line portions of FIG. 3*b*, is pulsating and unidirectional in character, as indicated by the solid-line curve 38. The total cathode current i_c is, therefore, a composite of the main discharge current I, which is represented in FIG. 3*b* by the clear area under the curve 38, and the auxiliary current *i* as represented by the hatched area. In this manner current is caused to flow from the main electrode 20 even during that portion of the cycle when the polarity at that end of the lamp 10 becomes positive and the main electrode 20 would ordinarily function as an anode. Thus, the current from each of the main electrodes 20 and 21 is maintained uni-

directional and above a preselected minimum value i_c (min.) thereby maintaining at all times a normal cathode fall voltage which exceeds the excitation potential of the gas used in the lamp **10**, as for example, argon in the case of a conventional type mercury-argon fluorescent lamp, and substantially eliminating the "ignition" and "extinction" noise incident with discharge current values below i_c (min.). When the polarity of the applied voltage again becomes negative at the beginning of the next cycle, the main electrode **20** by virtue of its superior electron-emissivity again functions as the cathode for the main discharge and the foregoing series of events is repeated.

As shown in FIG. 3*c*, the auxiliary electrodes **22** and **23** by virtue of acting as the anodes for both the main and auxiliary discharges handle a total current equivalent to the sum of the current flow effected by these discharges. This total anode current may be designated i_a and is represented by the cross-hatched area enclosed by the solid-line portions **40** of the current wave-forms during the cathode and anode half cycles and includes the auxiliary discharge current i which circulates in the branch circuit at one end of the lamp **10** and the main discharge current I received from the opposite end of the lamp.

It will be obvious that in place of a choke **26** a battery or any other means capable of storing and releasing electrical energy may be employed to achieve the foregoing results. Also, other types of construction, shapes and materials may be employed in fabricating the auxiliary and main electrodes without departing from the spirit of the invention.

From the foregoing it will be apparent that each of the main electrodes **20** and **21** are continuously operated as cathodes while the lamp **10** as a whole functions as an A.C. device in the regular manner. This is achieved by operating the main electrodes **20** and **21** as part of two separate D.C. circuits, that is, as parts of the branch or auxiliary circuits above-described. In other words, the auxiliary discharge current i while traversing part of the energizing circuit does not constitute a part of the main discharge current I but circulates entirely within the branch circuit, that is, from the main electrode **20** to the auxiliary electrode **22** and back again to the main electrode **20** by means of the contact pin **18**, conductor **36** and the portion of the main energizing circuit conductor **29** which includes the choke **26** and pin **16**.

It will thus be apparent that by providing a "D.C.-operated cathode" in an A.C.-operated gaseous discharge device in the manner above-described the current from each of the main electrodes **20** and **21** may be maintained at such a value that the generation of radio-frequency "ignition" and "extinction" noise normally incident with the decrease of current below this value will be substantially eliminated. While the critical current value below which radio-frequency radiation of such character will be generated depends upon the type of device involved and the operating characteristics of the individual cathode, it has been observed that in the case of conventional 420 ma. cathodes of the type normally employed in 40 watt fluorescent lamps the critical current value is about 50 ma. when the cathodes are operated at approximately their normal average current. Hence, in the practical case of a 60 cycle 0.42 ampere fluorescent lamp of the 40 watt size, the provision of an inductance of about 0.3 henry as the electrical-storage element in the energizing and auxiliary portions of the operating circuit will produce an auxiliary discharge having a constant voltage drop of about 11 volts which, in turn, will provide a minimum cathode current i_c (min.) of about 0.116 ampere with a power-dissipation of about 2 watts. However, the efficiency of the lamp will be comparable to that of a standard type lamp inasmuch as the auxiliary discharges will increase the light output at the lamp ends and increase the ionization thereat resulting in a substantial reduction in the anode drop of the main discharge.

In FIG. 4 there is illustrated graphically the peak "RF" noise spectrum of a lamp incorporating the "D.C.-operated cathode" of this invention compared to the most noise-free of the standard type of lamp heretofore employed. In order to condense the data to workable form the values are plotted on log-log scale with the noise intensity, that is, the electric field parallel to the lamp at a distance of one foot produced by the radio-frequency radiation emanating from the lamp as measured in terms of the number of microvolts per meter per kilocycle of bandwith, plotted along the ordinate, versus the frequency in megacycles, plotted along the abscissa. Accordingly, the magnitude of the difference between the curves is in reality much greater than that indicated by the slope and separation of the lines as here plotted. In other words, the noise intensity within the standard broadcast band was reduced on the average from about 250 microvolts to about 1.5 microvolts by fabricating and operating the lamp in accordance with the invention, the latter value being barely measurable and incapable of producing any noticeable or objectionable amount of radio-interference under the field conditions which prevail in most of the applications where fluorescent lamps are employed.

It will be recognized from the foregoing that the objects of the invention have been achieved by providing a gaseous discharge apparatus of such character that through the utilization of structural and circuit means conveniently and economically fabricated, the most pronounced components of radio-interference normally generated by operating the device from an A.C. power source are substantially eliminated.

While in accordance with the patent statutes one best known embodiment of the invention has been illustrated and described in detail, it is to be particularly understood that the invention is not limited thereto or thereby.

I claim:

1. Electric discharge apparatus comprising an envelope containing an ionizable medium, arc-supporting means within said envelope between which a gaseous discharge occurs during the operation of said apparatus, said arc-supporting means comprising a plurality of main electrodes, at least one of which is thermionic, and a plurality of auxiliary electrodes disposed adjacent to and in paired relation with said main electrodes to constitute a plurality of main-and-auxiliary electrode pairs, said auxiliary electrodes being less electron-emissive than said main electrodes, circuit means for connecting the main and auxiliary electrode in each pair to each other and to an alternating potential, and an electrical-energy storage means in said circuit means between the input side thereof operable and each of said main electrodes to sustain during the operation of said apparatus a D.C. auxiliary discharge between each of said main electrodes and its adjacent auxiliary electrode of such duration that the current from each of the said main electrodes is maintained unidirectional and above a predetermined value, whereby the generation of high-frequency radiation incident with the fall of the main electrode current below said value is substantially eliminated.

2. A light-generating system comprising a fluorescent lamp and an energizing circuit for operating said lamp from an A.C. power source, said lamp comprising a sealed light-transmitting envelope containing an ionizable medium, arc-supporting means within said envelope and connected to said energizing circuit between which a gaseous discharge occurs during the operation of said lamp, said arc-supporting means including two main electrodes arranged in remotely-spaced relation within said envelope and an auxiliary electrode adjacent each of said main electrodes, at least one of said main electrodes being thermionic and said auxiliary electrodes being less electron-emissive than the main electrode to which it is adjacent, a coating of phosphor on the inner surface of said envelope, two branch circuits connecting each of the said

auxiliary electrodes with its main electrode and said energizing circuit and in conjunction with a portion of said energizing circuit constituting an auxiliary circuit at each end of the lamp, and an inductance in each portion of the energizing circuit common to said auxiliary circuit, said inductance being connected in series with the main electrode and operable in response to the decrease in the main electrode current during the operation of said lamp to initiate and sustain an intermittent D.C. auxiliary discharge between each of the said main electrodes and its auxiliary electrode of sufficient magnitude and duration that the current from each of the said main electrodes is maintained above a predetermined value during the portion of each cycle when it would otherwise drop below said value to zero and said main electrode function as an anode, whereby each of the said main electrodes are continuously operated as cathodes and at a current of sufficient magnitude to minimize the generation of high-frequency radiation incident with the fall of the cathode current below a predetermined lower value.

3. In an electric discharge apparatus including a gaseous discharge device and an energizing circuit for operating said device from an alternating voltage source, said device containing a plurality of main electrodes and generating when operated an objectionable amount of radio interference; means for suppressing the radio interference incident with the operation of said device comprising: an auxiliary electrode adjacent each of the said main electrodes; a branch circuit connecting each of the said auxiliary electrodes with its main electrode and energizing circuit and in conjunction with a part of said energizing circuit constituting an auxiliary circuit; and electrical-energy storage means in said auxiliary circuit operable to initiate and sustain between each of the said main electrodes and its adjacent auxiliary electrode during the operation of said device an auxiliary discharge of sufficient intensity and duration to maintain the current from each of said main electrodes above a predetermined value during the portion of each cycle when the main electrode current would normally drop below said value to zero and said main electrode operate as an anode, each said auxiliary electrode being less electron-emissive than the main electrode proximate thereto and adapted thereby to function as anodes for both the main and auxiliary discharges.

4. In an A.C.-powered fluorescent lighting system including a fluorescent lamp which generated an objectionable amount of radio-frequency radiation during operation and contains a plurality of spaced main electrodes; means for substantially eliminating the radio interference incident with the operation of said lamp comprising: an auxiliary electrode adjacent each of said main electrodes, each said auxiliary electrode being less electron-emissive than the main electrode to which it is adjacent; an energizing circuit for connecting said main electrodes to an alternating potential; an auxiliary circuit connecting each of said auxiliary electrodes with the adjacent one of said main electrodes and with said energizing circuit; and an inductance in each of the said auxiliary circuits connected in series with the associated one of said main electrodes and operable in response to the decrease of electron current from said one main electrode incident with the cyclic reversal of the applied voltage to establish and maintain an auxiliary discharge between said one main electrode and its adjacent auxiliary electrode of such duration that the main electrodes are continuously operated as cathodes and supply a current which is unidirectional and maintained above a predetermined value even during that portion of the cycle when the main electrode current would normally fall below said value to zero and said main electrodes function as anodes, said auxiliary electrodes being adapted by virtue of their lower electron-emissivity to function as the anodes for both the auxiliary and main discharges.

5. Electric discharge apparatus comprising, an envelope containing an ionizable medium, a plurality of main electrodes within said envelope between which a gaseous discharge occurs during the operation of said apparatus, a plurality of auxiliary electrodes disposed adjacent to and in paired relationship with said main electrodes, at least one of said main electrodes being thermionic and said auxiliary electrodes being less electron-emissive than the main electrode with which it is paired, circuit means for connecting each of the paired main and auxiliary electrodes to each other and adapted to be connected to an alternating voltage source, an electrical-energy storage means in said circuit means between the input side thereof and each of said main electrodes operable to store part of the operating voltage during each half cycle of operation of said apparatus and then apply such stored voltage across the associated pair of said main and auxiliary electrodes later in the same half cycle of operation and thereby produce an intermittent auxiliary discharge therebetween of such duration and magnitude that the current from said main electrodes is maintained unidirectional and above a predetermined value during each cycle of operation of said apparatus.

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