Jan. 14, 1941. J. D. LE VAN 2,228,276

ELECTRICAL GASEOUS DISCHARGE DEVICE

Original Filed April 10, 1937

Fig. 1.

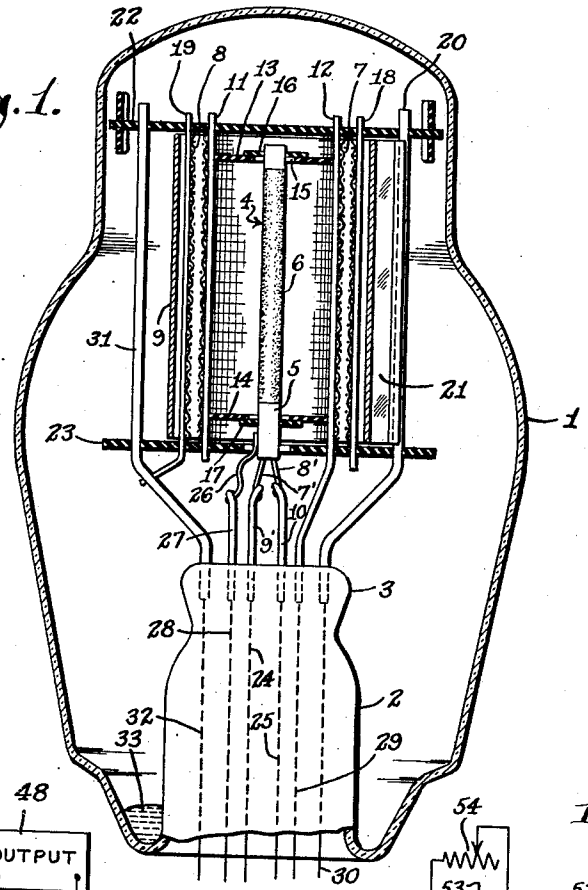


Fig. 2.

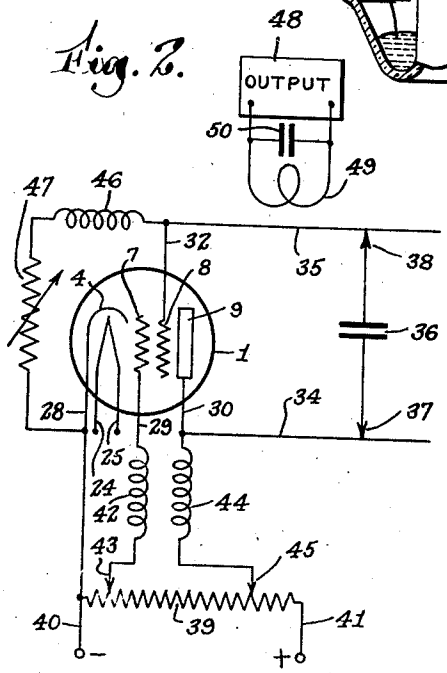
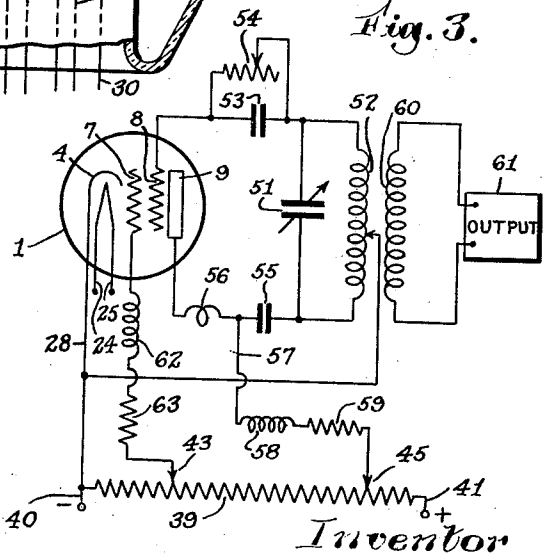


Fig. 3.



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2,228,276

ELECTRICAL GASEOUS DISCHARGE DEVICE

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Application April 10, 1937, Serial No. 136,159
Renewed May 11, 1940

13 Claims. (Cl. 250—36)

This invention relates to gaseous discharge tubes and to systems utilizing the same.

One of the objects of the invention is to produce an electrical discharge between two electrodes in an ionizable gas with very low voltage drop or even zero voltage drop.

Another object is to increase the efficiency of gaseous discharge tubes, particularly those in which an ionized gaseous discharge serves as a source of current carriers for a controlled space discharge.

The foregoing and other objects of my invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying diagrammatic drawing wherein:

Fig. 1 is a cross-sectional view of a tube with which my invention may be practised;

Fig. 2 is a diagram illustrating an embodiment of my novel system; and

Fig. 3 is another diagram illustrating another embodiment of my invention.

In Fig. 1 the gaseous discharge tube which I prefer to utilize consists of a gas-filled envelope 1, preferably of glass, having a reentrant stem 2, the upper end of which carries a press 3 in which are sealed a number of lead-in electrode supporting wires. Above the press and within the envelope 1 are supported a number of electrodes. One of these electrodes consists of a cathode 4. This cathode is of the usual type of indirectly-heated cathode ordinarily used in vacuum tubes, and consists of a hollow metal cylinder 5 coated on the exterior thereof with electron-emitting material 6, such as, for example, the oxides of alkali earth metals. The coating is heated to thermionic emission by means of an internal heater consisting usually of a coil of fine wire. The two ends of the heating filament 7' and 8' are connected to the two wires 9' and 10 sealed in the press 3. Surrounding the cathode 4 is the so-called cathanode 7. This cathanode consists of an extended electrode having perforations over its surface, and preferably is in the form of a fine wire grid. Surrounding the cathanode 7 and substantially concentric therewith is the control element 8 which likewise consists of an electrode of substantial area having perforations over its surface and which is preferably in the form of a fine wire grid. Surrounding all of the other electrodes and substantially concentric therewith is the anode 9 which is preferably formed of a thin solid metal plate. The cathanode is preferably supported in position by means of supporting standards 11 and 12. Two plates 13 and 14 close the upper and lower open ends of the cylindrical cathanode 7. The plates 13 and 14 have an opening 15 in the center thereof through which the cathode 4 passes freely. The cathode 4 is supported from the two plates 13 and 14 by means of insulators 16 and 17. The control electrode 8 is supported by supporting standards 18 and 19 while the anode 9 is supported from a supporting standard 20 by having a radial member 21 extending from said anode 9 and engaging said supporting standard 20. All of said electrodes are maintained in a definite relative position by the two insulating plates 22 and 23, which have small openings which receive the upper and lower ends respectively of the various supporting standards. External connections to the heating filament are made through wires 24 and 25 connected to the lead-in wires 9' and 10, respectively. An external connection is made to the cathode 4 by means of a cathode lead 26 welded to the lead-in wire 27 to which an external conductor 28 is connected. The supporting standard 12 for the cathanode 7 has its lower end sealed in the press 3, and has an external conductor 29 connected thereto, thereby establishing an external connection to said cathanode. The supporting standard 20 for the anode 9 also has its lower end sealed in the press 3, and an external conductor 30 connected thereto establishes an external connection for said anode. An additional supporting standard 31 whose lower end is sealed in the press 3 passes through openings in the upper and lower insulating members 22 and 23, respectively, and serves as an additional support for the electrode structure. The lower end of the supporting standard 19 of the control electrode 8 is welded to the supporting standard 31. An external conductor 32 connected thereto establishes an external connection to the control element 8. The envelope 1 is evacuated in accordance with the usual vacuum technique. After the tube has been evacuated, it is filled with a gas filling, such as helium or mercury vapor. The gas pressure of the filling may vary over a relatively wide range. However, this gas pressure is sufficiently high so that ionization can be produced therein to the degree as will be described below. When a vapor is used, such as mercury vapor, a quantity of mercury 33 is introduced into the tube. I have operated tubes in accordance with this invention at mercury vapor pressures of the order of ten microns and noble gas pressures of the order of 100 to 300 microns. It is to be understood that any gas

pressure which will produce the results herein described could be used.

The tube as described above may be made to operate substantially in accordance with the principles as set forth in my patent, No. 1,962,159, granted June 12, 1934. By initially establishing a discharge between the cathode 4 and the cathanode 7, the gas in the space between said two electrodes is ionized. A large number of the electrons which pass into the gaseous discharge space between the cathode and the cathanode and flow toward the cathanode 7 will pass through the screen openings in said cathanode, and once having gotten into the space outside of said cathanode, will come under the influence of the control electrode 8. The spacing between the anode 9 and the cathanode 7 is such that under the pressure conditions existing in the tube, the distance between the opposing electrode surfaces is of the order of magnitude of the mean free path of the molecules in the gas. Due to this spacing, a comparatively large voltage can be impressed across these electrodes without producing a self-sustaining independent ionizing discharge therebetween. With this spacing, any discharges which occur between the anodes 9 and the cathanode 7 are directly the result of electrons which pass from the gaseous discharge space through the openings in the cathanode 7. Under these conditions a complete control of this discharge can be secured by a potential on the control member 8.

I have found that in a tube of the type described, a certain type of operation can be secured wherein the discharge between the cathode 4 and the cathanode 7 passes with a very low voltage between these electrodes, which voltage in some cases may be zero. In some cases this discharge carrying a current considerably greater in value than a space charge limited current passes at these low voltages with no visible discharge in the cathode-cathanode space. By "visible discharge" is meant a discharge which liberates radiations to such an extent that they are readily visible to the human eye. A discharge which is not thus readily visible may be termed a "dark discharge."

One circuit in which this type of operation occurs is shown in Fig. 2. In this circuit the heating filament is supplied with heating current by connecting wires 24 and 25 to some suitable source of heating current not shown. The control grid 8 and the anode 9 are connected in a high frequency oscillating circuit by having the wires 30 and 32 connected to the extended conductors 34 and 35, respectively. A condenser 36 is connected between the conductors 34 and 35 by the adjustable connections 37 and 38. In this way the condenser can be moved along the conductors 34 and 35, thereby tuning the oscillating circuit to various frequencies. I have found that in a particular instance frequencies of the order of 10^8 c. p. s. were suitable. This is about 2.5 meters wave length. A suitable source of potential, such as a potentiometer, connected by conductors 40 and 41 across a 550 volt supply line, may be utilized to supply the proper potentials to the tube elements. The cathode 4 is connected by the conductor 28 to the negative terminal of the potentiometer. The cathanode 7 is connected through a high frequency choke 42 to an adjustable tap 43 on the potentiometer while the anode 9 is connected through a high frequency choke 44 to another adjustable tap 45 on the potentiometer. The control grid 8 is connected through a high frequency choke 46 and an adjustable resistance 47 to the conductor 28 of the cathode 4. This resistance is of a relatively low value, for example, 100 ohms or less, whereby a suitable negative bias is created on said control grid 8.

When the circuit described above is energized, oscillations are produced in the circuit of the condenser 36, which oscillations may be utilized in any suitable output device 48 coupled to the oscillating circuit by means of a coupling coil 49. The coil 49 may be tuned to the oscillator frequency by a condenser 50.

When the tube as shown oscillates, I have found that the voltage drop between the cathode 4 and the cathanode 7 falls to a very low value. In a particular case tap 43 was moved so that the voltage impressed between the cathode 4 and the cathanode 7 was two volts, which is less than the ionization voltage of the gases used, and a current of 175 milliamperes flowed between the cathode and cathanode. This was not the limiting value of this current, but was the value determined by the resistance in the potentiometer. Under these conditions, the luminous discharge disappeared in the cathode-cathanode space, but a faint luminous discharge was observed in the space between the control grid 8 and the anode 9.

In accordance with my present understanding of the theory of operation of this device, the phenomena which are involved are as follows. When the device is initially energized, the operation is substantially that as described above, in which electrons generated in the space between the cathode 4 and the cathanode 7 pass into the controlled space and come under the influence of the control electrode 8. The cathanode 7, the control grid 8, and the anode 9 then constitute a triode system, which connected to the oscillating circuit causes oscillations to be generated therein. The chokes 42, 44 and 46 serve to keep these oscillations out of the portions of the circuit where they are undesirable. The choke 44 particularly causes the oscillations produced to vary the voltage at the anode 9. The resistance 47 keeps the control grid 8 at an average potential relatively close to that of the cathode 4, while the choke 46 causes the oscillations produced to vary the potential of the grid 8 with respect to this average value. Under these conditions the oscillating circuit comprises the control grid 8, the anode 9, the conductor 34, the condenser 36, and the conductors 35 and 32 in series. The oscillations generated in this circuit periodically cause the anode 9 to become highly positive with respect to the control grid 8. While the anode is becoming more positive, at the same time the grid is becoming more negative so that the voltage between these electrodes may reach a comparatively high value. Within the same period of oscillation, however, the anode becomes less positive and the control grid becomes less negative so that the potentials on these electrodes may reach approximately the same value so that substantially no potential exists between them.

The theory of operation further contemplates that the electrons which enter the controlled discharge space through the openings in the cathanode 7, and also through the openings in the control grid 8, come under the influence of the positive potential on the anode 9, and produce some positive ions in the space between the control electrode 8 and the anode 9. This ionization, however, is not of sufficient extent to completely neutralize the space charge in the controlled

space so that the control electrode 8 still operates in the proper manner. When the tube is oscillating, as pointed out above, during one portion of the oscillation cycle, the anode 9 becomes highly positive with respect to the control grid 8. Under these conditions the positive ions created in the control grid anode space are accelerated toward the control grid 8. Under static conditions, substantially all of these positive ions would be captured either by the control grid 8 or by the cathanode 7. However, at the high frequencies which are used, the flight time of positive ions as they pass from the vicinity of the anode 9 to the vicinity of the control grid 8 is of the order of magnitude of the time of a single oscillation period. The constants of the circuit and the spacing between the control grid 8 and the anode 9 are so chosen that this relationship occurs. In the tube which I used to obtain the results specified above, the spacing between the control grid 8 and the anode 9 is about .030 inch. Therefore by the time a positive ion which is accelerated by the control grid 8 reaches said control grid, the voltage of that grid will have changed so that it is no longer highly negative with respect to the anode 9. This potential condition permits the positive ions, accelerated as described above, to readily slide through the openings in the control grid 8. These positive ions, therefore, leave the control grid 8 at a relatively high speed, which may be of the order of 1000 volts under the conditions which I have specified. These high speed positive ions also appear to pass readily through the openings in the cathanode 7, due probably to the fact that the ionization in the cathode-cathanode region permits the field of the cathode to reach through the openings in the cathanode 7. Under these conditions, as I have stated, the positive ions pass readily through the openings in the cathanode 7, and therefore enter the cathode-cathanode space at a relatively high speed. These positive ions then continue across the cathode-cathanode space to the cathode, whereupon they constitute a positive ion current to the cathode. In their passage through this space, these positive ions substantially entirely neutralize the space charge therein and permit large numbers of electrons to pass through this space with substantially no potential drop therein. From the above it will be seen that the discharge between the cathode 4 and the cathanode 7, which supplies electrons to the controlled discharge space, can occur in accordance with the present invention without any substantial expenditure of energy in this space.

Although I have described an oscillating circuit wiah a wave length of about 2½ meters above, a considerably different frequency from this can be used provided the relationships which I have specified still hold true. For example, in a tube with the same spacing as that used in the previous circuit, I have secured the same results with a wave-length of about 25½ meters. A circuit in which this frequency was used is shown in Fig. 3. In Fig. 3 those elements which are identical with those shown in Fig. 2 are numbered with the same reference numbers. In Fig. 3 the oscillating circuit consists of an adjustable condenser 51 connected across the terminals of an induction coil 52. One end of this circuit is connected through a condenser 53 to the control grid 8. An adjustable leakage resistance 54 is connected across the condenser 53 in order to impress upon the control a proper bias potential upon the control grid 8. The other end of the oscillating circuit is connected through a condenser 55 and a coil 56 consisting of a few turns. The condenser 55 prevents the positive potential applied to the anode 9 from also being applied to the grid 8. I have found that without the coil 56 certain parasitic oscillations were produced while with this coil 56 such parasitics were prevented from occurring. The desired positive potential is impressed upon the anode 9 by a conductor 57 connected from a point between the condenser 55 and the coil 56 through a high frequency choke 58, and a current-controlling resistance 59 to the adjustable tap 45 on the potentiometer 39. A coil 60 is coupled to the oscillating coil 52, whereby the output of the oscillator may be led to any suitable output device 61. The cathanode 7 is connected through a high frequency choke 62 and a current-controlling resistance 63 to the adjustable tap 43.

When the circuit described above is energized, oscillations are produced in the oscillating circuit 51, 52. At the wave length or frequency which I have described, the same phenomena which occurred in connection with Fig. 2 likewise occurred in this arrangement, namely, that the cathode-cathanode space became dark while a slight glow appeared in the control grid anode space, and also a considerable amount of current flowed between the cathode-cathanode under very low voltage conditions.

In the particular instance which I have mentioned, I moved the adjustable tap 43 so that the cathanode 7 was at the same potential as the cathode 4. Under these conditions a considerable amount of current flowed from the cathode to the cathanode, which current could be varied simply by varying the magnitude of the current-controlling resistance 63. The potentiometer was further adjusted so that the cathanode 7 was made negative with respect to the cathode 4. Even with a voltage of —13 volts on the cathanode, current still flowed in the same direction as previously from the cathode to the cathanode, although its magnitude was considerably reduced. Thus it will be seen that in accordance with this invention, the drop across the cathode-cathanode space can be made substantially zero, and some current will flow even when the cathanode is negative with respect to the cathode.

Of course it is to be understood that this invention is not limited to the particular details of construction and operation as described above as many equivalents will suggest themselves to those skilled in the art. We see that the present invention presents a means whereby current can be conducted across a gaseous discharge space at very low voltage drop, and consequently very low loss. Thus this arrangement could be utilized in connection with amplifiers, rectifiers, and various other types of gaseous discharge devices. In the case of a rectifier, the voltage to be rectified could be impressed directly across the cathode and cathanode, in which case the cathanode would constitute the anode of the rectifier system. Likewise various other methods of producing positive ions and accelerating them into the cathode-cathanode space for the purpose of neutralizing the space charge might be developed.

Various other changes in my system will readily suggest themselves. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. In an electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, another electrode, a gaseous filling at a pressure at which ionization of said filling at the applied voltages may occur, and means for generating positive ions outside of the space between said cathode and additional electrode, the method which comprises generating positive ions in said outside space and passing said positive ions into said space in sufficient numbers and sufficient velocity to substantially entirely neutralize therein the negative space charge of the electrons emitted from said cathode.

2. In an electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, another electrode, a gaseous filling at a pressure at which ionization of said filling at the applied voltages may occur, and means for generating positive ions outside of the space between said cathode and additional electrode, the method which comprises generating positive ions in said outside space and passing said positive ions into said space in sufficient numbers and sufficient velocity to cause a current of electrons to flow from said cathode to said additional electrode at voltages below the ionization voltage of said gaseous filling and without the occurrence of a visible discharge therein in the discharge space between said cathode and additional electrode.

3. An electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, another electrode, a gaseous filling at a pressure at which ionization of said filling at the applied voltages may occur, and means for generating positive ions outside of the space between said cathode and additional electrode and for passing said positive ions into said space, comprising a perforated electrode and a cooperating electrode spaced therefrom, and means for impressing a high frequency potential between them in such a way that the cooperating electrode becomes periodically positive with respect to said perforated electrode and then substantially less positive with respect to said perforated electrode, the spacing between said perforated electrode and said cooperating electrode being of the order of magnitude such that the time a positive ion takes to travel between said cooperating electrodes and said perforated electrode is of the order of magnitude of the time of one cycle of said high frequency potential.

4. An electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, another electrode, a gaseous filling at a pressure at which ionization of said filling at the applied voltages may occur, and means for generating positive ions outside of the space between said cathode and additional electrode and for passing said positive ions into said space, comprising a perforated electrode and a cooperating electrode spaced therefrom, and means for impressing a high frequency potential between them in such a way that the cooperating electrode becomes periodically positive with respect to said perforated electrode and then substantially less positive with respect to said perforated electrode, the spacing between said perforated electrode and said cooperating electrode being of the order of magnitude of the mean free path of molecules of said gaseous filling, the frequency of said high frequency potential being such that the time of one cycle thereof is of the order of magnitude of the time a positive ion takes to travel between said cooperating electrode and said perforated electrode.

5. In an electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, a perforated cathanode surrounding said cathode, a grid surrounding said cathanode, and an anode surrounding said grid, the method which comprises generating positive ions in the space between said grid and anode and passing said positive ions into the space between said cathode and cathanode in sufficient numbers and sufficient velocity to substantially entirely neutralize therein the negative space charge of the electrons emitted from said cathode by impressing a high frequency potential between said anode and grid, so that the anode becomes periodically positive with respect to said grid and then substantially less positive with respect to said grid, said high frequency potential being of such a magnitude and periodicity to produce said ionization in the space between said anode and grid.

6. An electrical gaseous discharge device comprising an envelope containing an electron emissive cathode, a perforated cathanode surrounding said cathode, a grid surrounding said cathanode, and an anode surrounding said grid, means for generating positive ions outside of the space between said cathode and cathanode and for passing said positive ions into said space, and means for impressing a high frequency potential between them in such a way that the anode becomes periodically positive with respect to said grid and then substantially less positive with respect to said grid, the spacing between said grid and said anode being of the order of magnitude such that the time a positive ion takes to travel between said anode and said grid is of the order of magnitude of the time of one cycle of said high frequency potential.

7. An electrical gaseous discharge device comprising an envelope containing an electron emissive cathode, a perforated cathanode surrounding said cathode, a grid surrounding said cathanode, and an anode surrounding said grid, means for generating positive ions outside of the space between said cathode and cathanode and for passing said positive ions into said space, and means for impressing a high frequency potential between them in such a way that the anode becomes periodically positive with respect to said grid, the spacing between said grid and said anode being of the order of magnitude of the mean free path of molecules of said gaseous filling, the frequency of said high frequency potential being such that the time of one cycle thereof is of the order of magnitude of the time a positive ion takes to travel between said anode and said grid.

8. An electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, another electrode, a gaseous filling at a substantial pressure, means for establishing said other electrode at a positive direct current potential with respect to said cathode in the region from zero to a value substantially less than the ionization voltage of said gaseous filling, and means for generating positive ions outside of the space between said cathode and other electrode and for passing said positive ions into said space in sufficient numbers and sufficient velocity to cause a current of electrons to flow from said cathode to said electrode at said potential sub-

stantially less than the ionization voltage of said gaseous filling.

9. An electrical gaseous discharge device comprising an envelope containing a gaseous filling at a substantial pressure, an electron emissive cathode, a perforated cathanode spaced from said cathode, a grid adjacent said cathanode, and an anode adjacent said grid, means for establishing said cathanode at a positive direct current potential with respect to said cathode in the region from zero to a value substantially less than the ionization voltage of said gaseous filling, means for impressing a high frequency potential between said anode and grid, and means for causing a substantial high frequency voltage to appear between said cathanode and cathode comprising a substantial high frequency impedance interposed between said cathanode and said cathode.

10. An electrical gaseous discharge device comprising an envelope containing a gaseous filling at a substantial pressure, an electron emissive cathode, a perforated cathanode surrounding said cathode, a grid surrounding said cathanode, and an anode surrounding said grid, means for establishing said cathanode at a positive direct current potential with respect to said cathode in the region from zero to a value substantially less than the ionization voltage of said gaseous filling, means for impressing a high frequency potential between said anode and grid, and means for causing a substantial high frequency voltage to appear between said cathanode and cathode comprising a substantial high frequency impedance interposed between said cathanode and said cathode.

11. In an electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, another electrode, a gaseous filling in said envelope at a pressure at which ionization of said filling at the applied voltages may occur, and means including a voltage source for producing ionization of said gaseous filling outside of the space between said cathode and additional electrode and for passing positive ions from said outside space into said space in sufficient numbers and sufficient velocity to substantially entirely neutralize therein the negative space charge of the electrons emitted from said cathode to the extent that the voltage drop between said cathode and additional electrode becomes substantially less than the ionization voltage of said gaseous filling.

12. In an electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, another electrode, a gaseous filling in said envelope at a pressure at which ionization of said filling at the applied voltages may occur, and means including a voltage source for producing ionization of said gaseous filling outside of the space between said cathode and additional electrode and for passing said positive ions from said outside space into said space in sufficient numbers and sufficient velocity to cause a current of electrons to flow from said cathode to said additional electrode at voltages below the ionization voltage of said gaseous filling and without the occurrence of a visible discharge therein in the discharge space between said cathode and additional electrode.

13. In an electrical gaseous discharge device comprising an envelope containing an electron-emissive cathode, a perforated cathanode surrounding said cathode, a grid surrounding said cathanode, and an anode surrounding said grid, means for impressing a high frequency potential between said anode and grid to make the anode periodically positive with respect to said grid, and then substantially less positive with respect to said grid, said high frequency potential being of such a magnitude and periodicity to produce ionization in the space between said anode and grid, and to pass positive ions into the space between said cathode and cathanode in sufficient numbers and sufficient velocity to substantially entirely neutralize therein the negative space charge of the electrons emitted from said cathode.

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