

July 27, 1937.

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2,088,249

GASEOUS RECTIFIER

Original Filed Aug. 4, 1931

2 Sheets-Sheet 1

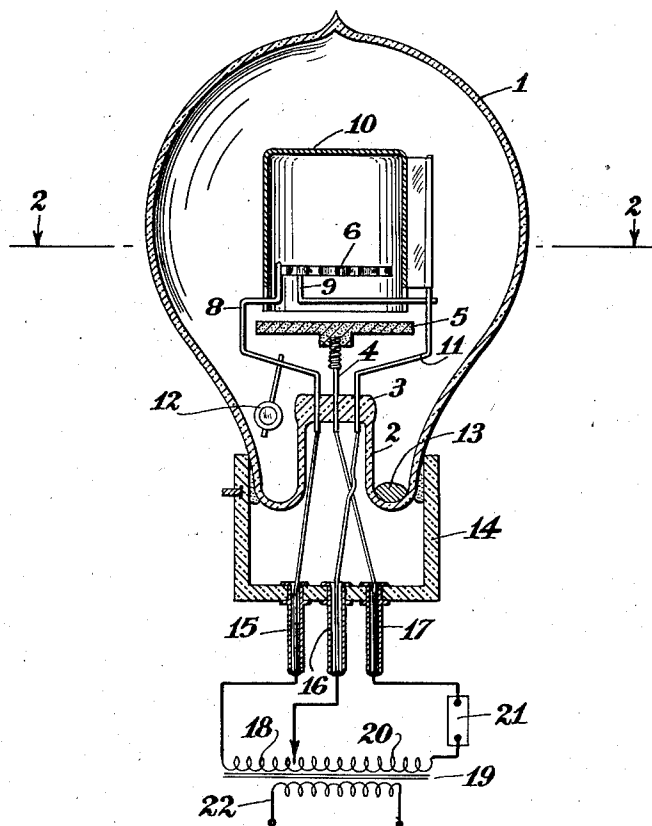


Fig. 1.

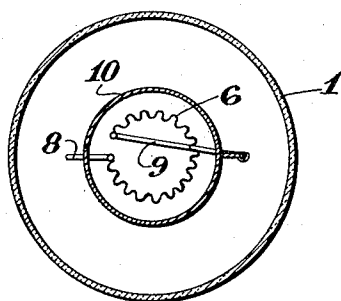


Fig. 2.

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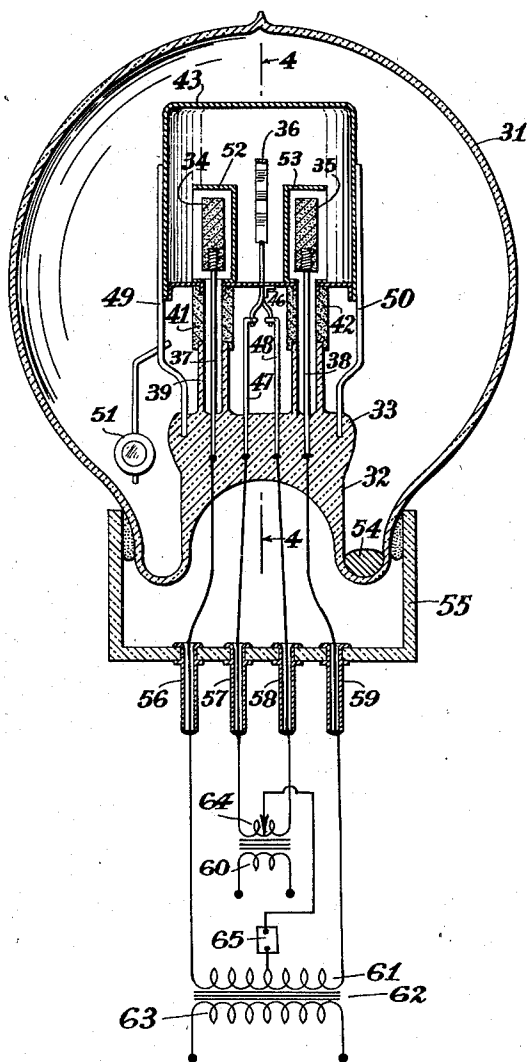


Fig. 3.

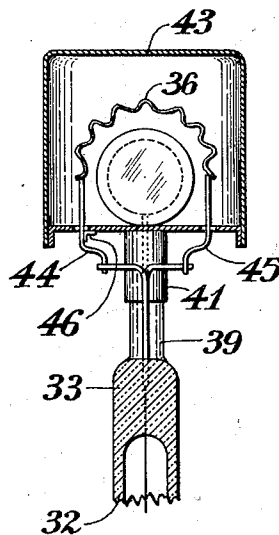


Fig. 4.

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GASEOUS RECTIFIER

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Application August 4, 1931, Serial No. 555,005
Renewed November 21, 1936

4 Claims. (Cl. 250—27.5)

This invention relates to rectifiers, and more particularly to those rectifiers which operate with an ionizing discharge in a gas or vapor.

Among the objects of my invention is the provision of such a rectifier which can rectify higher voltages without breakdown in the non-conducting direction, and which operates at increased efficiency.

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 drawings, wherein:

Fig. 1 is a cross-sectional view of one embodiment of my invention;

Fig. 2 is a section taken along line 2—2 of Fig. 1;

Fig. 3 is a cross-section of another embodiment of my invention; and

Fig. 4 is a section taken along line 4—4 of Fig. 3.

In rectifiers which operate with an ionizing discharge through a gas, it is desired to conduct electricity through the gas when the cathode is negative and the anode is positive, while when the polarity is reversed, no conduction should occur. The amount of voltage which such a rectifier can rectify depends upon the value of voltage which can be impressed between the anode and cathode on said reverse of polarity without a breakdown discharge occurring between said electrodes. Heretofore rectifiers of this type when subjected to an alternating voltage have broken down in the non-conducting or reverse direction at voltages considerably lower than such a rectifier would be able to withstand if a direct voltage were initially impressed across the anode and the cathode in said reverse direction. This breakdown discharge usually occurs between the cathode and anode leads as they enter the sealed bulb from the press. According to my present understanding of the phenomena involved, breakdown discharges of the above kind occur for the following reasons. In all gases and vapors there exists a number of free electrons even under conditions where no outside electrical stress is impressed on said gases and vapors. When a voltage is applied across such an atmosphere, as for example the atmosphere between the anode and cathode leads of a rectifier, the free electrons will be accelerated by the voltage. If the voltage is large enough, the electrons will attain sufficient velocity to ionize a neutral atom upon collision therewith, thereby liberating additional electrons.

When the number of electrons so liberated reaches a sufficiently large number, the resistance of the atmosphere to the passage of an electrical current falls to a very low value and a breakdown discharge will occur. The voltage which gas or vapor can withstand without breakdown decreases with an increase in the number of free electrons in that gas or vapor. As pointed out above, there are always some free electrons present in such atmospheres. However, if the normal number of electrons is increased by electron emission from any of the members within the atmosphere, such as, for example, the electrode leads, the breakdown voltage decreases. Emission from the anode lead is particularly effective in causing breakdown in the reverse direction in a rectifier. This is due to the fact that an electron emitted from the anode lead when the cathode is positive, will be attracted to the cathode and must pass through the gas or vapor in the intervening space. An electron emitted from the cathode lead under such conditions will immediately fall back on the cathode lead without having a chance to ionize any of the gas atoms.

I have discovered that electrons may be emitted from the anode lead, due to the following reasons. When an ionizing discharge occurs in a gaseous atmosphere, such as, for example, mercury vapor, a large number of atoms in the discharge space become excited and radiate the characteristic radiation of that gas which in mercury is of a wave length of 2536 Angstrom units. In ordinary rectifiers, this radiation diffuses through the gas within the tube, and is absorbed by atoms of that gas which in turn become excited. When an excited atom collides with the surface of some member, such as an anode or cathode lead, it is extremely likely to knock out an electron from that surface, due to the excitation energy which the atom possesses. The tendency to knock out an electron is very marked when the work function of the surface with which the excited atom collides is less than the excitation voltage of the excited atom. This relation usually exists between the work function of the cathode and anode leads and the excitation voltage of the gas filling in the tube. For example, in the case where nickel wires are used as the electrode leads and mercury vapor as the gas filling, the excitation voltage of the mercury atom is 4.9 volts while the work function of the nickel is 4.1 volts. Thus the nickel wires will often emit an electron when an excited mercury atom collides with

the surface of said nickel wires. The electron emission is also increased when the temperature of the wires is allowed to increase. In a rectifier, excitation of the gas atoms ordinarily occurs during the conducting half cycle, and ceases when the polarity reverses and the tube becomes non-conducting. However, it takes an appreciable length of time for the radiation to diffuse out of the gaseous atmosphere. This diffusion takes place, at least partly, by the following mechanism. An excited atom persists in its state of excitation for an appreciable length of time. The average length of time in which an excited atom persists in its excited state, in the case of mercury vapor, is 10^{-7} seconds. Since the atom possesses a definite average velocity dependent upon the temperature of the gas, it will travel a definite average distance during this time, after which it will emit the characteristic radiation. This radiation will travel out from the atom, and will be absorbed by a neighboring atom. This neighboring atom becomes excited, and likewise persists in the excited state for the same definite average length of time. This transmission of radiation from atom to atom continues until it is lost either by the radiation passing out through the walls of the tube, by being absorbed by the surfaces of the tube, or the surfaces of the electrode structure within said tube, or by an excited atom colliding inelastically with another atom or with one of the above surfaces. It will be appreciated that the length of time which it takes for the radiation to diffuse out of the gas is greater when the amount of gas through which it can diffuse is greater. When the radiation is allowed to diffuse through the whole tube, such as occurs in the ordinary rectifier tube, this time is so great that there are still an appreciable number of excited atoms within the gas when the reverse potential is applied between the electrodes. The presence of these excited atoms causes an appreciable number of electrons to be liberated from the electrode leads, as explained above. This number of atoms is sufficient to initiate a breakdown discharge between the leads when a voltage of sufficient value is impressed across them. However, if this liberation of electrons did not occur, a considerably greater voltage could be impressed across said elements without the discharge taking place.

In accordance with my invention, I eliminate the above cause of the breakdown of the rectifying tube by confining the radiation due to the discharge in a limited space, and by shielding the electrode leads against said radiation. I also find that the arrangement which I use produces a considerable increase in the efficiency of my rectifier.

Referring to Figs. 1 and 2, which show one embodiment of my invention, my rectifier comprises a sealed glass envelope 1, having a reentrant stem 2 formed with a press 3 at its upper end. Anode lead 4 sealed in said press supports an anode 5. This anode is preferably constructed of carbon. Cooperating with the anode 5 is a thermionic cathode 6. This cathode preferably comprises a metallic filament, such as, for example, nickel coated with some material to increase the electron emissivity of said filament. Such a coating may consist of barium or strontium oxide. The filament 6 is supported by two filament leads 8 and 9. The filament 6, as shown, preferably consists of a flat ribbon which is disposed edgewise with respect

to the anode 5. The anode 5 is in the form of a disk in a position between the thermionic cathode 6 and the press 3, so that said press and the wires sealed therein are shielded against any direct radiation coming from the discharge between the anode 5 and the cathode 6. In order to more completely shield the wires sealed in the press 3, a cap 10 is placed over the thermionic cathode 6. The cap 10 and anode 5 cooperate so as to practically entirely confine the radiations generated by the discharge between the electrodes. The cap 10 is supported by means of a standard 11 sealed in the press 3. The cathode lead 9 is welded to the standard 11 while the cathode lead 8 is also sealed in the press 3. A getter cup 12 which originally contains a mixture which liberates barium on heating may be supported from one of the wires sealed in the press 3, for example, the cathode lead 8. The various parts within the envelope are freed from occluded gases, and said envelope is evacuated in accordance with the usual practice. A quantity of mercury 13 is placed in the tube in order to furnish the desired mercury vapor atmosphere. The barium is freed from the getter cup 12, for example by inductive heating thereof. This barium cleans up the various residual impurities which exist in the tube, and some of the barium also amalgamates with the mercury. This barium amalgamated with the mercury acts continually as an active getter to clean up any impurities which may subsequently be liberated within the envelope 1. The envelope 1 may be provided with the usual base 14 carrying contact prongs 15, 16 and 17. The lead 8 and the standard 11 are provided with conductors which are connected to contact prongs 15 and 16, respectively, while the anode lead 4 is connected to contact prong 17. The rectifier as described may be connected to a suitable rectifying circuit which may be, for example, such as that shown in Fig. 1. The cathode 6 is provided with heating current from a section 18 of the secondary of a transformer 19. A source of relatively higher potential is impressed between the cathode 6 and the anode 4 by another section 20 of the secondary of said transformer 19. Some load device, indicated at 21, is connected in series in the cathode-anode circuit. The transformer 19 is provided with a suitable primary winding 22 which is connected to a source of alternating current.

When the rectifier is connected, as shown in Fig. 1, the section 18 will furnish heating current to the filament 6 which will be raised to a temperature at which it emits a large number of electrons. When the potential, due to the section 20 of the transformer, is in such a direction as to make the cathode 6 negative and the anode 5 positive, electrons coming from the cathode 6 will travel toward the anode 5. The electrons traveling in this direction will collide with the atoms of mercury which will exist throughout the tube, due to the presence of the mercury 13. The energy which these electrons will have gained, due to the potential between the electrodes, will usually be sufficient to cause the atoms with which they collide to be ionized. Thus, large numbers of electrons and positive ions will exist between the cathode and anode, and enable a large amount of current to pass with a comparatively low voltage drop. However, some of the atoms will not be entirely ionized, but will be put into an excited condition. These excited atoms will emit the radiation of λ 2536, the res-

onant radiation of the mercury atom. This radiation will diffuse throughout the vapor enclosed by the cap 10 and the anode 5. Due to the configuration of these elements, very little radiation will be allowed to escape from the space enclosed by said elements.

Within the cap 10 some of the excited atoms will collide with the surface of said cap, and liberate electrons therefrom in accordance with the explanation given in the early part of the specification. During the handling and operation of the device there may be a tendency for some of the barium to deposit upon the metallic surfaces with which it comes in contact, and thus some barium may be deposited upon the inside surface of the cap 10. Also any of the coating which is dislodged from the filament 6 during operation likewise tends to deposit upon the inside surface of the cap 10. These deposits lower the work function of the cap 10, and thus electrons are much more easily emitted from said cap upon bombardment by excited atoms. The configuration of the parts also tends to raise the temperature of the inside surface of the cap 10 to such a degree that some electrons are thermionically emitted from the barium-coated inner surface of said cap. Even without the presence of barium, the inner surface of the cap 10 emits a considerable number of electrons, yet the presence of the barium itself causes said cap to become a very good emitter of electrons. If the inside surface of said cap is oxidized, its affinity for the barium is greatly increased, and in some instances it may be desirable to so oxidize said surface. In order to take advantage of the electron emission of the cap 10, said cap is electrically connected to the cathode 6 by having the cathode lead 9 connected to the cap standard 11.

Due to the fact that the radiation is confined to the volume within the cap, a larger number of excited atoms per unit volume will exist within said volume than if the radiation were allowed to diffuse throughout the envelope 1. Thus the chance for an excited atom to absorb energy by collision with an accelerated electron or atom, or by the absorption of some radiant energy, is correspondingly increased. When an atom is in an excited condition, it requires but a slight additional amount of energy to ionize that atom. Therefore, the concentration of excited atoms within the discharge space, due to the enclosure by the cap 10, facilitates the ionization of these atoms. Thus liberation of electrons from the inner surface of the cap 10 and the increased ionization due to the concentration of excited atoms within said cap, enable the same amount of current to be drawn between the cathode and the anode with a lower voltage drop than would ordinarily be necessary. Therefore the losses are decreased and the efficiency of the tube is increased.

When the potential impressed between the anode 5 and the cathode 6 reverses in direction so that the anode 5 becomes negative and the cathode 6 positive, the discharge between said electrodes will cease. This is due to the fact that the anode 5 does not emit any electrons, and any electrons which are emitted from the cathode 6 will fall back thereon, due to the direction of the applied voltage. Since the radiation which was generated during the active half cycle is confined within the cap 10 and since the volume contained within said cap is comparatively small, the diffusion of said radiation to the walls of the cap 10 and the remaining structure surrounding

said confined space takes place in a comparatively short interval of time. By the time the voltage between the anode 5 and the cathode 6 reaches a value which would be sufficient to start a discharge if an appreciable number of electrons were being liberated from the anode structure, the radiation will have diffused to such an extent that an insignificant number of excited atoms are colliding with the anode structure. It should be noted, moreover, that the anode being made of carbon has a work function which is higher than the excitation voltage of the mercury vapor. Furthermore, barium does not seem to settle on such an anode, or if it does settle, it appears to be continually knocked off during the discharge. At all events, the tendency for electrons to be emitted from such an anode, due to the bombardment by excited atoms, is comparatively slight. The chief advantage of the confining of the radiation by the cap 10 in the structure shown in Fig. 1 during the inactive half cycle is that the anode lead 4 is shielded against bombardment by excited atoms. While the barium does not tend to settle on the anode 5 itself, yet it will be deposited upon the anode lead 4. Furthermore, since this anode lead is usually constructed of a metal, such as nickel, the work function of this lead is less than the excitation voltage of a mercury atom. The presence of barium on this lead lowers this work function still further. If excited atoms were allowed to collide with this lead during the inactive half cycle, a sufficient number of electrons would be liberated from said lead to initiate a breakdown discharge for certain values of reverse voltage. However, the structure as shown in Fig. 1 effectively shields anode lead 4 against bombardment by excited atoms, and therefore voltages which would otherwise produce a breakdown can be efficiently rectified.

It will be noted that the above arrangement also shields the leads as they emerge from the press 3 against heat radiations emitted by the filament 6. The maintaining of the leads at this point at a comparatively low temperature by shielding them against said heat radiations as well as against the characteristic radiations of the discharge undoubtedly is of considerable effect in preventing electron emission from the leads and in preventing breakdown discharges at this point.

I have constructed rectifiers, as shown in Fig. 1 above, with and without the cap 10. Without the cap 10 the rectifier could withstand back voltages up to 500 volts, and would pass a rectified current of two amperes with a voltage drop of five volts. However, when the cap 10 was used, the rectifier could withstand back voltages up to 800 volts, and could pass a rectified current of two amperes with a voltage drop of only three volts. Thus it can be seen that the shield, due to the cap 10 results in a considerable increase both in the amount of back voltage which the rectifier could withstand, and also in the efficiency of said rectifier.

While the number of electrons liberated from the anode itself, due to bombardment by excited atoms, is of comparatively little importance in a single wave rectifier, such as that shown in Fig. 1, yet this effect becomes appreciable when a full-wave rectifier having two or more anodes is used. This is due to the fact that in a single wave rectifier with an arrangement as shown in Fig. 1, the radiation has been practically entirely diffused by the time the reverse voltage is ap-

plied. In a double wave rectifier, however, there is a large number of excited atoms present when a reverse voltage is applied between one anode and the cathode. This is due to the fact that when the full reverse voltage is impressed between one anode and cathode, a discharge is occurring between the other anode and cathode. This discharge causes a large number of excited atoms to be generated, which excited atoms on colliding with the inactive anode tend to liberate a sufficiently large number of electrons to cause a breakdown in the reverse direction when the reverse voltage is of sufficient value.

In Fig. 3 I have shown an arrangement which decreases the effect of liberation of electrons from the anodes, due to the bombardment by excited atoms in a full-wave rectifier. Fig. 3 shows a sealed envelope 31 having a reentrant stem 32 carrying a press 33 at its upper end. The press 33 carries the electrode structure, including two anodes 34 and 35 and a cathode 36. The anodes 34 and 35 are preferably formed of carbon, and are supported respectively by anode leads 37 and 38 sealed in the press 33. The press 33 carries glass tubes 39 and 40 surrounding the anode leads 37 and 38, respectively, as they emerge from said press. The upper ends of the tubes 39 and 40 carry insulating tubes 41 and 42, respectively. Each of these insulating tubes is formed with a central hole through which the anode leads pass. A hollow member 43 enclosing the anodes 34 and 35 and the cathode 36 rests upon the upper ends of the insulating tubes 41 and 42. This hollow member is formed of thin metal, such as, for example, nickel or iron, and is provided in its lower wall with apertures in line with the openings in the glass and insulating tubes through which the anode leads 37 and 38 pass into the interior of said hollow member. The spacing between the anode leads and the openings in the wall of the hollow member 43 may be of the order of the mean free path of the gas in the tube in accordance with the patent to Smith, No. 1,617,179. The cathode 36 may be a thermionic filament of the kind as described for Fig. 2, and is positioned intermediate the two anodes 34 and 35. This cathode is supported at its opposite ends by two standards 44 and 45 which pass through openings in the bottom wall of the hollow member 43. One of the standards 44 may be electrically connected with the hollow member 43 by a connecting member 46. This member is preferably welded to both the standard 44 and the bottom wall of the hollow member 43. This arrangement also serves to help support the cathode. The standards 44 and 45 are connected respectively to two cathode leads 47 and 48 sealed in the press 33. The hollow member 43 is also firmly supported in the proper position by two standards 49 and 50 also sealed in the press 33. A getter cup 51 may be supported within the envelope 31 by being welded to one of the standards, for example 49. The anodes 34 and 35 are provided respectively with shields 52 and 53. These shields are in the form of cups so positioned that the open side thereof faces away from the cathode 36 and the other anode. These shields may be formed of any material opaque to the radiations generated by the discharge, but are preferably formed of a thin metal, such as nickel or iron. The shields are provided with an opening in one side thereof for the passage of the cathode leads 37 and 38, and are welded to the bottom wall of the hollow member 43 in such a position that the anode leads may pass through

said openings. As described for Fig. 1, envelope 31 is provided with a quantity of mercury 54 after the tube has been thoroughly freed of occluded gases, and has been evacuated in the usual manner. The getter cup 51 may contain a source of barium as does getter cup 12. The envelope 31 is provided with a base 55 carrying four contact prongs 56, 57, 58 and 59. The anode leads 37 and 38 are connected respectively to the contact prongs 56 and 59 while the two cathode leads 47 and 48 are connected respectively to the two contact prongs 57 and 58.

The tube as described in Fig. 3 may be provided with any suitable operating circuit, one of which may be as illustrated diagrammatically in Fig. 3. A source of heating current for the cathode 36 consists of a transformer 60 connected between the two contact prongs 57 and 58. A source of relatively higher potential is connected between the two anode leads 56 and 59. This source may consist of a secondary 61 of a transformer 62, the primary 63 of which is connected to a suitable source of alternating current. A connection is provided between the midpoint of the secondary 64 of the transformer 60 and the midpoint of the secondary 61. In this connection is placed any desirable load as indicated at 65.

The operation of the device, as shown in Fig. 3, is very similar to that as described for Fig. 2. It will be noted that the anode leads are very effectively shielded against bombardment by excited mercury atoms. In addition, however, each of the anodes is also shielded against such bombardment. When discharge occurs between one of the anodes, for example 34, and the cathode 36, such a discharge will cause radiations to be generated along the path of the discharge which extends from the cathode 36 around the edges of the shield 52 to the anode 34. Liberation of electrons may occur from the surface of the shield 52 as well as from the hollow member 43, due to the bombardment by excited atoms, as explained in reference to Fig. 2. Since each of these members is electrically connected to the cathode 36, the liberation of electrons therefrom will increase the efficiency of the rectifier. During such discharge it will be noted that the shield 53 and the adjacent wall of the hollow member 43 effectively shield the anode 35 against the radiations generated by the adjacent discharge. The number of excited atoms which will reach the surface of the anode 34 will be very small, due to the above arrangement. Due to the small number of excited atoms colliding with the surface of the anode 35 and due to the fact that this surface has a comparatively high work function, an insignificant number of electrons will be liberated from the anode 35 during said adjacent discharge. Upon reversal of potential, the discharge will shift from the anode 34 to the anode 35. However, the anode 34 will be protected by the shield 52 in the same manner as the anode 35 was protected by the shield 53.

It will be noted that the anodes 34 and 35 as well as their leads are also effectively shielded against heat radiations from the cathode 36. This shielding enables the anodes and their leads to be operated at comparatively low temperatures which further diminishes the possibility of electrons being emitted from either said anodes or their leads.

The arrangement as shown in Fig. 3 will enable the rectifier to operate at considerably higher voltages and with increased efficiency.

This invention is not limited to the particular details of construction, materials or processes described above, as many equivalents will suggest themselves to those skilled in the art.

- 5 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:

- 10 1. A space discharge device comprising a gas-tight envelope containing an ionizable atmosphere, an anode, and a thermionic cathode, said cathode and anode being adapted to support an ionizing discharge between them, said cathode
15 comprising an electron-emitting filament consisting of a flat conductor and a hollow conducting member electrically connected to and surrounding said flat conductor, and an opening of substantial size in said hollow member, said anode having a
20 surface of relatively high work function substantially closing said opening to prevent radiations and material liberated by the discharge from escaping from the space enclosed by said hollow member and said anode, said flat conductor being
25 disposed edgewise with respect to said anode, all of the discharges which occur in said device being confined to the space enclosed by said hollow member and anode.
- 30 2. A space discharge device comprising a gas-tight envelope containing an ionizable atmosphere, an anode and a thermionic cathode, said cathode and anode being adapted to support an ionizing discharge between them, said cathode
35 comprising a filament coated with a solid electron emissive coating adapted to be heated to a temperature of thermionic emission, and a hollow conducting member electrically connected to and surrounding said coated member, an opening
40 in said hollow member, said anode being disposed outside of said hollow member and having a surface substantially blocking said opening.

3. A space discharge device comprising a gas-

tight envelope containing an ionizable atmosphere, an anode, and a thermionic cathode, said cathode and anode being adapted to support an ionizing discharge between them, said cathode
5 comprising an electron-emitting filament consisting of a flat ribbon conductor, said conductor being crimped to increase the total length of filament within a predetermined space, a hollow
10 conducting member electrically connected to and surrounding said flat conductor, and an opening of substantial size in said hollow member, said anode having a surface of relatively high
15 work function substantially closing said opening to substantially prevent radiations and material liberated from the discharge from escaping from the space enclosed by said hollow member and
20 said anode, substantially all of the discharges which occur in said device being confined by the space enclosed by said hollow member and anode.

4. A space discharge device comprising a gas-
20 tight envelope containing an ionizable atmosphere, an anode, and a thermionic cathode, said cathode and anode being adapted to support an ionizing discharge between them, said cathode
25 comprising an electron-emitting filament consisting of a flat ribbon conductor, said conductor being crimped and wound in such a way as to increase the total length of filament within a
30 predetermined space, a hollow conducting member electrically connected to and surrounding said flat conductor, and an opening of substantial size in said hollow member, said anode hav-
35 ing a surface of relatively high work function substantially closing said opening to substantially prevent radiations and material liberated from the discharge from escaping from the space en-
40 closed by said hollow member and said anode, substantially all of the discharges which occur in said device being confined by the space enclosed by said hollow member and anode.

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