April 18, 1950 E. D. McARTHUR 2,504,713

LIGHT SENSITIVE ELECTRIC DISCHARGE DEVICE AND CONTROL CIRCUITS THEREFOR

Original Filed Sept. 24, 1942 2 Sheets-Sheet 1

Fig. 1.

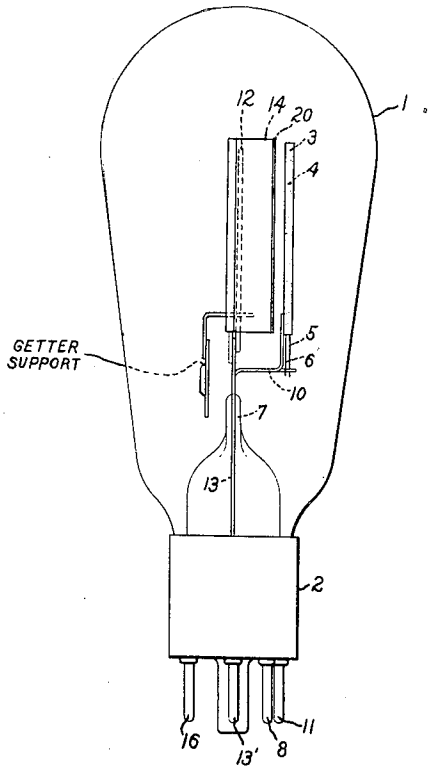



Fig. 2.

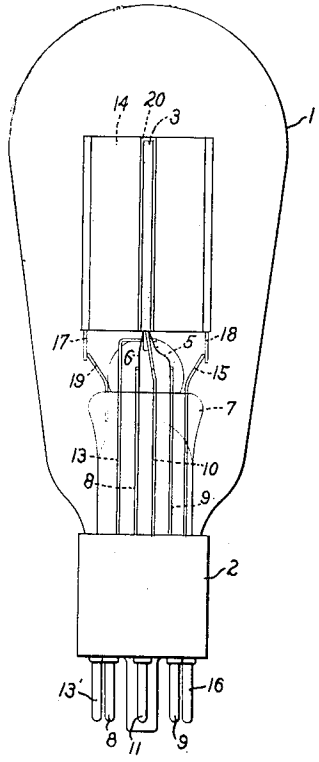



Fig. 3.

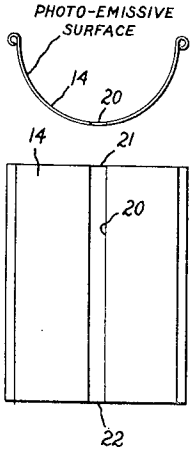
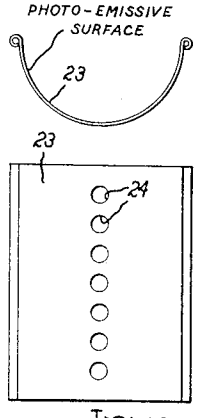



Fig. 4.




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Fig. 5.

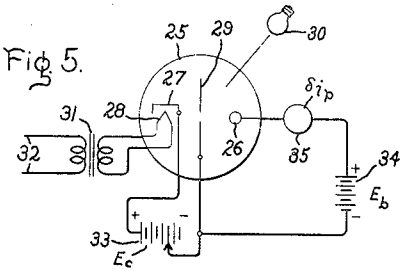



Fig. 6.

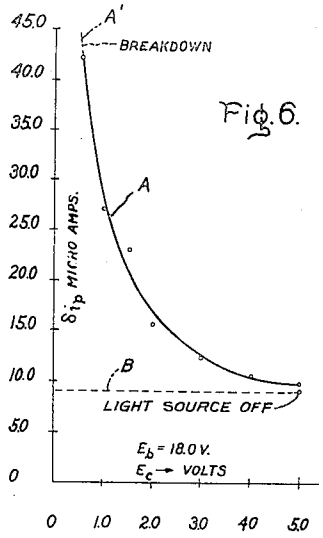



Fig. 7.

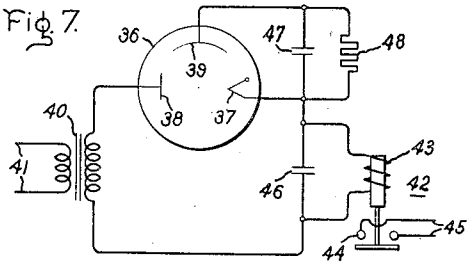



Fig. 8.

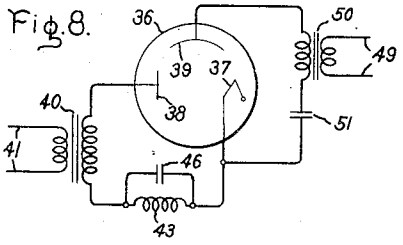



Fig. 9.

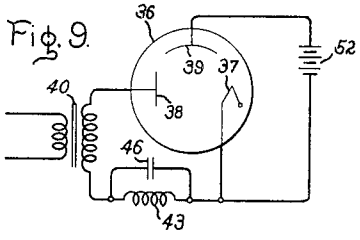



Fig. 10.

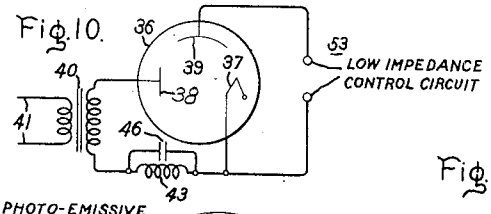



Fig. 11.

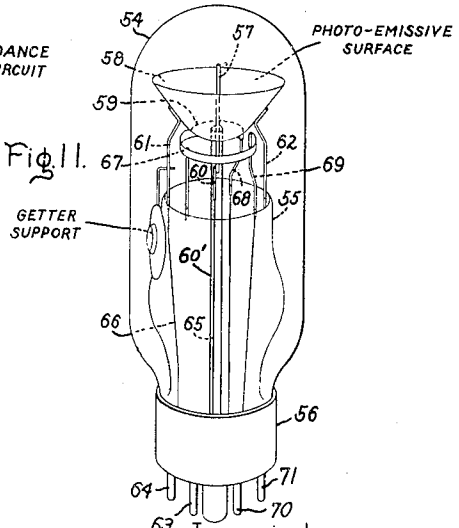
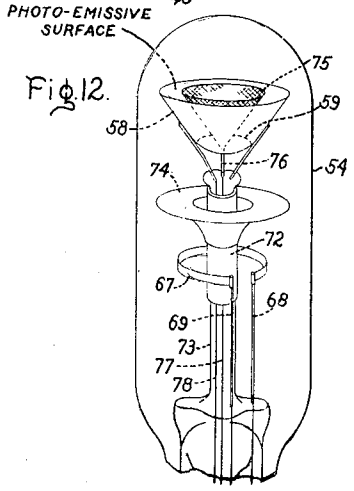



Fig. 12.




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# UNITED STATES PATENT OFFICE

2,504,713

## LIGHT SENSITIVE ELECTRIC DISCHARGE DEVICE AND CONTROL CIRCUITS THEREFOR

Elmer D. McArthur, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Original application September 24, 1942, Serial No. 459,532. Divided and this application September 11, 1944, Serial No. 553,528

9 Claims. (Cl. 250—211)

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My invention relates to light sensitive or photo-responsive electric discharge devices and control circuits or systems therefor. This application is a division of my Patent No. 2,434,622, issued January 13, 1948.

Heretofore, in photo-sensitive or photo-responsive circuits where it has been desired to effect a circuit controlling operation in response to light intensities, it has frequently been necessary to employ a conventional type photo-emissive electric discharge device with a highly sensitive voltage or current means, such as an electromagnetic relay, in order that sufficient actuating current or power is obtained to carry out the intended circuit controlling operation. For example, where it has been desired to actuate a mechanism of appreciable size, it has frequently been necessary to employ a highly sensitive electromagnetic type relay or equivalent device, resulting in a relatively expensive system which lacked the desired degree of flexibility in control or adjustment.

It is an object of my invention to provide new and improved light sensitive control systems.

It is another object of my invention to provide new and improved photo-emissive or light sensitive electric discharge devices.

It is a further object of my invention to provide new and improved photo-emissive or light sensitive electric discharge devices of the type employing ionizable mediums.

It is a still further object of my invention to provide new and improved electric discharge devices of the photo-emissive type wherein a high degree of sensitivity is obtained by electrode construction and configuration such that the thermal effect of the thermionic cathode upon the photo-emissive control member is substantially negligible.

It is a still further object of my invention to provide new and improved light sensitive or photo-emissive electric discharge devices of the controlled type which employ an ionizable medium and which are capable of operation in a manner so that the anode current is accurately controllable or adjustable within a region not effecting ionization of the medium and which also permits conduction of current between an anode and a cathode by an arc discharge when either the intensity of the light impinging on the light sensitive surface attains a predetermined value, or when the control member voltage is raised with respect to the cathode.

Briefly stated, in the illustrated embodiments of my invention I provide new and improved

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electric discharge devices of the light sensitive or photo-emissive type which comprise an anode, a cathode, and a photo-emissive or light sensitive electrostatic control member enclosed within an atmosphere of an ionizable medium such as an inert gas. The electrode configuration is such that the thermal effects of the thermionic cathode upon the photo-emissive control member are substantially minimized, thereby not appreciably affecting the emission characteristics of the control member. In this manner a greater sensitivity of control is obtained than that afforded by arrangements provided heretofore.

In accordance with a still further feature of my invention, I provide in light sensitive electric discharge devices of the above described type a heat shield which may be metallic and which is positioned between the thermionic cathode and the photo-sensitive control member, thereby absorbing a large percentage of the radiation and convection heat incident to the thermionic cathode and rendering the control member emission characteristics substantially independent of cathode temperature.

In accordance with a still further feature of my invention, I provide new and improved control circuits for electric discharge devices of the above-described type whereby appreciable power or current is available for the actuation of electromagnetic devices such as relays, etc. In accordance with a still further feature of my invention, I provide new and improved light sensitive electric discharge devices of the controlled type having a photo-emissive electrostatic control member the potential of which permits control or adjustment of the anode current for given values of light intensity impinging on the control member within a region of operation which does not effect appreciable ionization of the medium surrounding the electrodes. The potential of the electrostatic control member may also be controlled so that the medium does become ionized to establish an arc discharge between the anode and cathode in the event the intensity of the light impinging on the photo-emissive surface of the control member attains a predetermined value.

For a better understanding of my invention, reference may be had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims. Figs. 1 and 2 diagrammatically illustrate one embodiment of my invention which is a light sensitive electric discharge device of the controlled type; Figs. 3 and 4 dia-

grammatically illustrate alternative forms or configurations of the photo-sensitive electrostatic control member; Fig. 5 represents diagrammatically a light-sensitive system embodying one feature of my invention wherein the anode current of the discharge device may be controlled or adjusted within two separate regions, that is within a region where ionization of the medium is obtained and a second region wherein ionization is not produced. Fig. 6 represents certain operating characteristics of my invention, particularly the system shown in Fig. 5. Figs. 7–10 inclusive diagrammatically illustrate still further light-sensitive systems embodying features of my invention; Fig. 11 diagrammatically represents a still further embodiment of my invention wherein the electrode configuration is of different form than that illustrated in Figs. 1 and 3, and Fig. 12 illustrates a still further modification wherein a mesh type anode and a heat shield are provided.

Referring now to Figs. 1 and 2 of the drawings, my invention is there illustrated as comprising a light-sensitive or photo-sensitive electric discharge device of the controlled type including a plurality of electrodes mounted within a glass receptacle or bulb 1 mounted on a base member 2 and which acts as a support for the discharge device as a whole. The bulb 1 may contain an ionizable medium, such as an inert gas at the desired low pressure, and this operation may be effected by filling the exhausted bulb with a gas through a suitable glass tubulation (not shown) which is sealed off and which may lie within the base 2. For example, I may employ an atmosphere of argon at a pressure of substantially 100 to 150 microns. It will be appreciated that I may employ other inert gases such as neon and xenon, etc. if desired. I provide within the enclosure of the bulb 1 a thermionic cathode 3 of elongated form and which may be constructed of an electron emissive material such as tungsten, thoriated tungsten, or the like. Alternatively, the cathode 3 may be constructed of a metal, such as nickel, which is coated with an alkaline earth metal 4 or an oxide thereof to increase the electron emissivity. A cathode heating-element (not shown) extends into the interior of the cylindrical cathode 3, and cathode heating-element terminals 5 and 6, also shown in Fig. 2, are provided. A glass press 7 supports and seals conductors 8 and 9 which are connected to terminals 5 and 6. A cathode conductor 10 is also supported by and sealed in the glass press 7 and is terminated in the metallic prong or conductor 11 which is also attached to the base 2.

I provide an anode 12 which may be of elongated configuration, such as a metallic cylinder or rod having its principal dimension or length substantially parallel with that of the thermionic cathode 3 and which is of relatively small area. A conductor and supporting member 13 for the anode 12 is supported by and sealed in the glass press 7 and is terminated in an externally accessible conductor 13′ attached to the base 2. Of course, it is to be appreciated that other forms of anode structure may be employed.

In order to control the anode current and to provide means which is light-sensitive, I provide a photo-emissive electrostatic control member 14 which is connected in spaced relation between the cathode 3 and the anode 12 and may be supported by a stem or conductor 15 which is in turn supported by and sealed in the glass press 7 and made externally accessible by means of a conductor 16 which is supported by the base 2. A rigid construction of the control member 14 and the supporting means therefor may comprise supporting members 17 and 18 which may be welded or soldered to the control member 14 and one of which, such as supporting member 18, may be attached or welded to conductor 15 and the other of which may be supported by the member 19 which is embedded or anchored in the glass press 7.

The photo-emissive electrostatic control member 14 is coated with a material to provide a high degree of photo-emissivity. For example, the electrostatic control member 14 may comprise an oxidized silver base over which a layer of caesium is applied. Of course, other photo-emissive metals or alloys may be employed. The control member 14 in one modification of my invention is preferably of semi-cylindrical configuration being concave to the anode 12 and convex toward the cathode 3. Furthermore, the area of the control member 14 is great as compared with that of the cathode 3 so that the thermal effects of the thermionic cathode 3 upon the emission characteristics and control characteristics of the control member 14 are substantially negligible. Stated in other words, the projected area of the cathode 3 upon the surface of the control member is very small.

The light sensitive surface of control member 14 may be placed upon the concave portion of control member 14 facing the anode 12 and may be deposited thereon in the usual or conventional manner. One detail view of the form of the control member 14 is illustrated in Fig. 3 where the portion of the control member nearest the cathode 3 is provided with an elongated aperture 20 which is substantially co-extensive with the principal dimension of the cathode 3. When such a configuration of the control member is employed, it will be appreciated that some means is required to support the two sections of the control member and to accomplish this result I may employ semi-circular conductors 21 and 22 which are welded or soldered to the control member 14.

An alternative form of the photo-emissive electrostatic control member is shown in Fig. 4 wherein a semi-cylindrical control member 23 is provided with a series of vertically spaced apertures 24 in a line which is substantially co-extensive with the principal dimension or height of the thermionic cathode 3.

It will be appreciated that in both of the arrangements illustrated in Figs. 3 and 4, the projected area of the thermionic cathode on the photo-sensitive control member is relatively small, approaching zero as a limit in the arrangement shown in Fig. 3. In this manner, the thermal effect of the cathode on the control member are minimized, and at the same time there is provided an appreciable path for the arc discharge which is established under certain conditions of operation between the anode 12 and the cathode 3. The operation of the embodiment of my invention illustrated in Figs. 1 and 2 may be more fully appreciated by referring to the circuit arrangement shown in Fig. 5 wherein the photo-emissive or light sensitive electric discharge device 25 is diagrammatically illustrated and may be constructed to comprise the structural features described above with particular reference to Figs. 1 and 2. In the arrangement of Fig. 5, the electric discharge device 25 is illustrated as comprising an anode 26, a thermionic

cathode 27 having a heating element 28, and a photo-emissive electrostatic control member 29 which may be subjected to light of different intensities derived from a source which is diagrammatically illustrated as comprising a lamp 30.

The cathode heating element 28 may be energized from any suitable source of current such as a transformer 31 energized from an alternating current supply circuit 32. An adjustable biasing potential, such as a negative unidirectional biasing potential, may be impressed upon the control member 29 by means of a battery 33. The output circuit of the discharge device 25 which comprises the anode 26 may be energized from a suitable source of current, such as a battery 34, to supply various amounts of unidirectional current to a load device 35 in accordance with the conditions of operation controlled by the discharge device 25.

Although the output circuit of the discharge device 25 may be connected in the manner illustrated in Fig. 5, that is connected across the anode 26 and the control member 29, it will be appreciated in view of the various modifications of my invention explained hereinafter that the output circuit may be connected across the anode and cathode.

Apparatus embodying the embodiments of my invention may be operated in several ways. One way in which electric discharge devices of the type described above may be employed is by the adjustment of the negative unidirectional biasing potential to effect current flow between the anode 26 and the control member 29 of adjustable or controllable value in response to the intensity of the light impinging upon the photo-emissive surface of control member 29. That is, by the adjustment of the magnitude of the biasing potential the anode current may be established to have different values, depending upon the magnitude of the biasing potential. Within this region of operation, the medium is ionized but not sufficiently to produce an arc discharge. Furthermore, the magnitude of the biasing potential may be adjusted so that the current within the discharge device varies as a function of the intensity of the light impinging on the electrode 29.

A still further way in which the electric discharge device may be operated is by establishing the magnitude of the unidirectional biasing potential to a value which, acting in conjunction with a given intensity of impinging light, effects ionization of the medium and establishes an arc discharge within the device.

The various operating characteristics of electric discharge devices constructed in accordance with the principles of my invention may be more fully appreciated by referring to the characteristics illustrated in Fig. 6 wherein the solid portion of curve A represents the variation of the anode current $\delta ip$ of the discharge device 25 for a given intensity of light applied to the light sensitive surface of control member 29. The dotted curve B represents the amount of current which would flow between the control member 29 and anode 26 with no light present. It is emphasized that upon application of light to the control member 29, the magnitude of the current which flows is substantially increased but may be adjusted throughout an appreciable region within which the electron flow is not sufficient to effect ionization of the medium by collision with the ions of the medium. The dotted extension A' of curve A represents that region of operation



within which the medium becomes ionized to effect the establishment of an arc discharge. This type of operation may be effected by a relative decrease in the magnitude of the unidirectional biasing potential, or by an increase in the intensity of light which impinges on control member 29, or may be obtained by the joint action of two such controlling influences. For example, referring to the characteristics shown in Fig. 6, ionization of the medium occurs when the bias potential impressed on grid 29 is reduced to a value somewhat less than 1 volt for a given intensity of light impinging upon the control member. It is apparent that if the bias potential is maintained constant and the intensity of the light increased, the breakdown or the ionization of the medium would occur at a point determined by the joint action of these two quantities.

With a plate voltage of substantially twenty volts and a negative biasing potential of three volts for the characteristics illustrated in Fig. 6, I have also found that the medium becomes ionized to effect an arc discharge for a particular intensity of light employed.

Fig. 7 illustrates a still further embodiment which may employ electric discharge devices of the type described above, and is diagrammatically illustrated as including an electric discharge device 36 comprising a thermionic cathode 37, an anode 38, and a photo-emissive electrostatic control member 39. These latter mentioned elements may have configurations similar to those shown in Figs. 1 and 2 and may also take the form of the elements shown in Figs. 11 and 12 to be described presently. I provide means for impressing across the anode 38 and cathode 37 of the discharge device 36 an alternating potential which may be furnished by means of a transformer 40 energized from an alternating current circuit 41. A load device, such as a relay 42, may be connected to be energized in accordance with the anode-cathode current and may comprise an actuating coil 43 and contacts 44 which are connected to control a circuit 45. In order to maintain the current through the coil 43 at a substantially constant value so long as the operation of the discharge device 36 dictates energization thereof, I may connect a capacitance 46 across the actuating coil 43.

A suitable biasing potential may be impressed on control member 39 and may be of the self-rectifying type comprising a parallel connected capacitance 47 and a resistance 48. These latter mentioned elements serve to produce a negative unidirectional biasing potential during each inverse half cycle of the anode-cathode voltage due to the control member rectification characteristic so that at the beginning of each positive half cycle the discharge device 36 is in a condition to discriminate as to the intensity of the light which impinges upon its photo-emissive surface.

One way in which the arrangement of my invention shown in Fig. 7 may be employed is as a means for detecting various intensities of light and for operating the relay 42 when the light intensity attains a predetermined value. So long as the light intensity remains below a predetermined value, the negative biasing potential established by capacitance 47 and resistance 48 is sufficient to maintain the electron flow from the control member 39 to the anode 38 at a value sufficiently below that which effects ionization of the medium and below that which effects operation of relay 42. However, if the photo-

electric current reaches a value sufficient to cause ionization of the medium upon impingement of a light of a predetermined intensity, an arc discharge will be established between anode 38 and cathode 37, causing the flow of appreciable current to actuate coil 43 of relay 42, thereby causing the relay to close its contacts 44. So long as the light intensity remains above this predetermined value, current will be transmitted to the actuating coil 42 during each positive half cycle of voltage applied to anode 38, and the capacitance 46 serves to maintain the current through the actuating coil substantially constant even during negative half cycles. However, if the light intensity decreases to a value below that which effects the reinitiation of arc discharges during each positive half cycle, the anode-cathode current flow will not continue and the charge of capacitance 46 will be dissipated causing coil 42 to be deenergized or sufficiently reduced in energization, thereby opening contacts 44.

A still further modification of my invention is illustrated in Fig. 8 which is similar in many respects to that shown in Fig. 7 and corresponding elements have been assigned like reference numerals. In the modification of Fig. 8 a separate source of biasing potential, such as an alternating current source 49, is employed to impress a biasing potential across control member 39 and cathode 37 through a transformer 50. The alternating bias voltage is preferably adjusted to be 180 electrical degrees out of phase with the anode-cathode voltage, and the secondary winding of transformer 50 is connected in series relation with a capacitance 51.

During each inverse half cycle of anode-cathode voltage, the voltage produced by transformer 50 establishes a biasing potential on control member 39 by charging the capacitance 51, the current for producing this charge being obtained by virtue of the electron emission current which flows between control member 39 and cathode 37. If the intensity of the light increases sufficiently to increase the photo-emissive current to a value which effects ionization of the medium and establishes an arc discharge when the anode 38 becomes positive during its cyclic variation in potential, anode-cathode current will flow effecting energization of the load device which may be actuating coil 42. In this manner, it will be appreciated that the negative biasing potential is established during each negative half cycle of anode-cathode voltage. The discharge of capacitance 51 facilitates establishment of the arc discharge within device 36. This type of operation will be effected when the increase of light intensity occurs during a positive half cycle or during a negative half cycle of applied anode-cathode voltage. When the initiation of the increased light intensity occurs during a negative half cycle, the ionization effect is sufficient to carry over into the succeeding positive half cycle so that current flow is produced in the anode-cathode circuit.

A further embodiment of my invention is illustrated in Fig. 9 which is similar in many respects to Fig. 7, and corresponding elements have been assigned like reference numerals. Instead of employing an alternating current circuit for establishing the voltage difference between the cathode 37 and the control member 39, I may employ a unidirectional source such as a battery 52. In this arrangement, when the light intensity attains a predetermined value, an arc discharge will be initiated and current flow will be established in the anode-cathode circuit.

One of the principal features of light sensitive electric discharge devices built in accordance with my invention is that the control circuit which establishes the sensitivity of the initiation of operation may be a low impedance circuit and not one which functions principally in response to potential. By the provision of such a device and system, it is possible to obtain greater degrees of sensitivity than that afforded by many of the prior art arrangements, particularly where it is desired to employ the device and the system in a climate which is subjected to extreme variations in atmospheric conditions such as variations in relative humidity and temperature which would tend to produce condensation of moisture on high voltage elements comprising the sensitive part of the circuit, thereby reducing its sensitivity.

In Fig. 10 I have diagrammatically illustrated a still further embodiment of my invention wherein a low impedance control circuit 53 is connected across the control member 39 and cathode 37 of electric discharge device 36, the initiation of the arc discharge or operation of the device being effected by the current which flows between control member 39 and cathode 37. That is, the circuit is primarily a current responsive circuit and does not depend appreciably upon large voltage variations, thereby dispensing with the employment of impedance elements of relatively high value which in turn effect or cause the presence of relatively high voltages.

Fig. 11 diagrammatically illustrates a still further modification of my invention, particularly a new and improved light sensitive electric discharge device which employs an ionizable medium such as an inert gas, and a plurality of electrodes including an electrostatic photo-emissive control member. Referring particularly to the electric discharge device shown in Fig. 11, it comprises an enclosing receptacle such as a glass bulb 54 which may include a cylindrical type glass press 55 which is sealed at the desired pressure. The glass bulb 54 may be evacuated and gas-filled through a tubulation (not shown). The bulb 54 is supported by a base 56. I provide a photo-emissive electrostatic control member 58 which surrounds an appreciable dimension of a wire anode 57, and which may be an inverted truncated-cone having a photo-emissive surface on the concave portion thereof facing the anode. The control member 58 is constructed to have a lower opening 59 through which the anode 57 extends. Anode 57 and control member 58 may be supported above the glass press 55 by uprights 60, 61, and 62, respectively. Anode 57 and upright 60 may be supported by a vitreous or glass sleeve or pencil 60' in which these members and conductors 65 are embedded or sealed. The uprights 60 and 61 are connected to prongs 63 and 64 through conductors 65 and 66, respectively which may be sealed in the glass press 55.

I provide a thermionic cathode preferably constructed of a metallic ribbon 67 having thermionic emissive characteristics and which may have a substantially circular configuration lying in a plane substantially perpendicular to the principal axis of the anode 57. The cathode 67 may be supported by wire uprights 68 and 69 which in turn are sealed in the glass press 55 and made externally accessible by prongs or conductors 70 and 71 which are supported by base 56. It will be noted that the projected area of cathode ribbon 67 upon the surface of the control member 58 is inappreciable so that the thermal effects of

the cathode do not materially affect the emission characteristics of the control member 58.

In operation, the embodiment of my invention shown in Fig. 11 functions substantially the same as that explained above in connection with Figs. 1, 2, and 5.

In the modification of my invention shown in Fig. 12, which is similar in many respects to that shown in Fig. 11 and corresponding elements have been assigned like reference numerals, I provide a heat shield in spaced relation between the thermionic ribbon cathode 67 and the photo-emissive electrostatic control member 58. This heat shield may be constructed of metal such as nickel or copper having an appreciable thermal capacity to absorb heat which is radiated from the cathode 67. The heat shield may comprise a metallic cylinder 72 supported upon a pencil or glass stem 73 and may be sealed thereto by employing an alloy of iron-nickel-cobalt. The portion of the shield which extends toward the control member 58 may comprise a flared or flanged section including a metallic annular member 74 which lies in a plane substantially perpendicular to the direction of heat flow or heat radiation between members 67 and 58. Conductors 77 and 78, which are connected to anode 75 and control member 58, may extend through and be sealed in the glass stem 73, and may be made externally accessible by means of a base (not shown).

In the modification of my invention shown in Fig. 12, I provide an anode which may take the form of an inverted cone 75 and may be constructed of a wire mesh or grid and which is supported at the vertex thereof by means of an upright 76 which extends through the lower opening 59 in the control member 58. The concave portion or surface of the control member 58 is also coated with a photo-emissive material and the initiation of current between the anode and cathode may be accomplished in the same manner, as explained above, in connection with the devices shown in Figs. 1, 2, 5, and 11.

While I have shown and described my invention as applied to particular systems employing various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention and I therefore aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A circuit comprising a light sensitive electric discharge device including a plurality of electrodes enclosed within an ionizable gaseous medium, said electrodes including an anode, a cathode and a photo-emissive electrostatic control member for controlling the flow of current between said anode and cathode, a source of alternating anode voltage connected between said anode and cathode for causing an anode current to flow in said device, means connected to said control member for establishing and applying thereto a self-biasing voltage responsive to energization of said circuit for controlling the flow of said anode current, said self-biasing voltage and said anode voltage being mutually proportioned at values insufficient to establish an ionized gaseous discharge in said discharge device, and photo-emissive means affixed to said control member whereby the potential of said control member may be raised responsive to the impingement of light thereon to a value sufficient to establish an ionized gaseous discharge in said discharge device.



2. A circuit as in claim 1 in which said first mentioned means comprises a capacitor connected to said control member.

3. A circuit as in claim 1 in which said first mentioned means comprises a resistor and a capacitor in a parallel circuit connected in series with said control member.

4. A circuit as in claim 1 including relay means selectively responsive to an ionized gaseous discharge in said device.

5. A circuit comprising a light sensitive electric discharge device including a plurality of electrodes enclosed within an ionizable medium, said electrodes including an anode, a cathode and a photo-emissive electrostatic control member, a source of alternating anode voltage connected between said anode and cathode for causing an anode current to flow in said device, a source of alternating control voltage and means responsive thereto for establishing and applying to said control member a self-biasing voltage connected to said control member for controlling the flow of said anode current, said self-biasing voltage and said anode voltage being mutually proportioned at values insufficient to establish an ionized discharge in said discharge device, and photo-emissive means affixed to said control member whereby the potential of said control member may be raised responsive to the impingement of light thereon to a value sufficient to establish an ionized discharge in said discharge device.

6. A circuit as in claim 5 in which said first mentioned means comprises a capacitor in series with said source of alternating control voltage and said control member.

7. A circuit as in claim 5 in which said first mentioned means comprises a resistor and a capacitor in a parallel circuit connected in series with said control member.

8. A circuit as in claim 5 in which said alternating control voltage is displaced in phase substantially 180 electrical degrees with respect to said anode voltage whereby said biasing voltage is established by flow of current between said cathode and control member during inverse half cycles of said anode voltage.

9. A circuit as in claim 5 including relay means selectively responsive to an ionized gaseous discharge in said device.

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