Sept. 22, 1942. P. H. CRAIG ET AL 2,296,269

PHOTOELECTRIC ELECTRONIC TUBE

Filed May 13, 1940 2 Sheets-Sheet 1

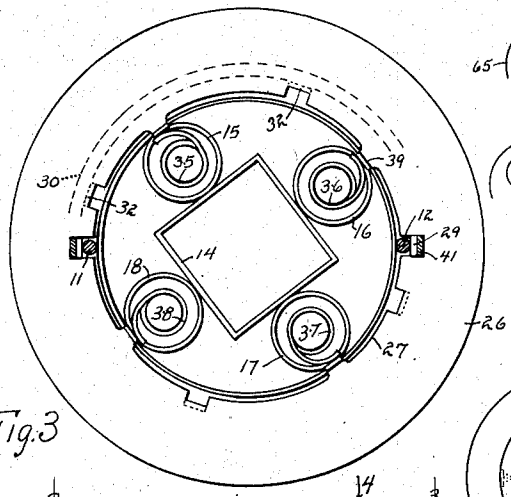



Fig. 3

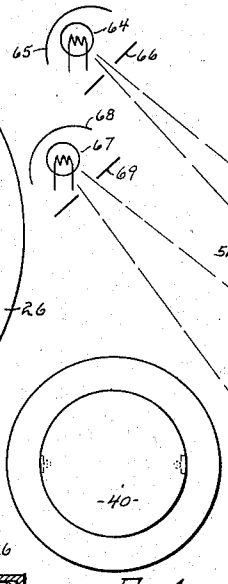



Fig. 4

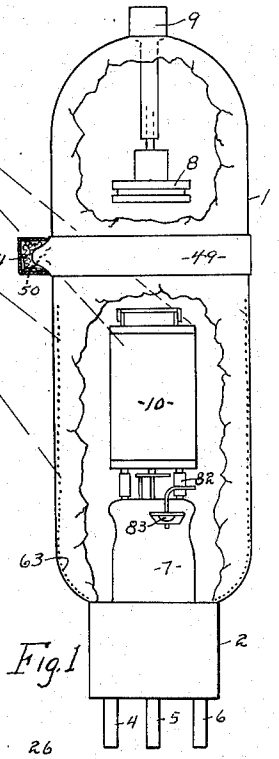



Fig. 1

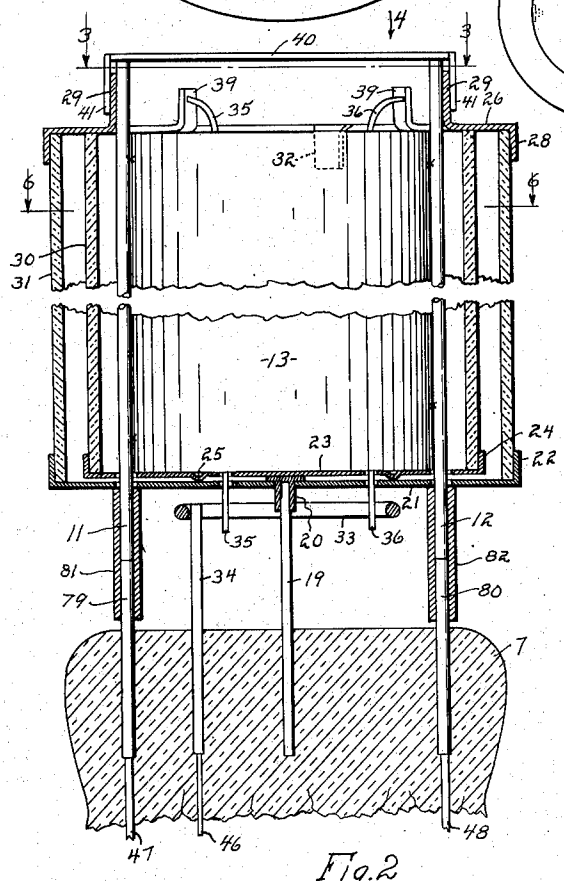



Fig. 2

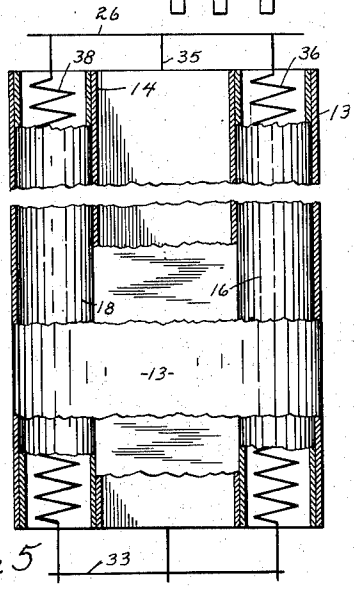



Fig. 5

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PHOTOELECTRIC ELECTRONIC TUBE

Filed May 13, 1940 2 Sheets-Sheet 2

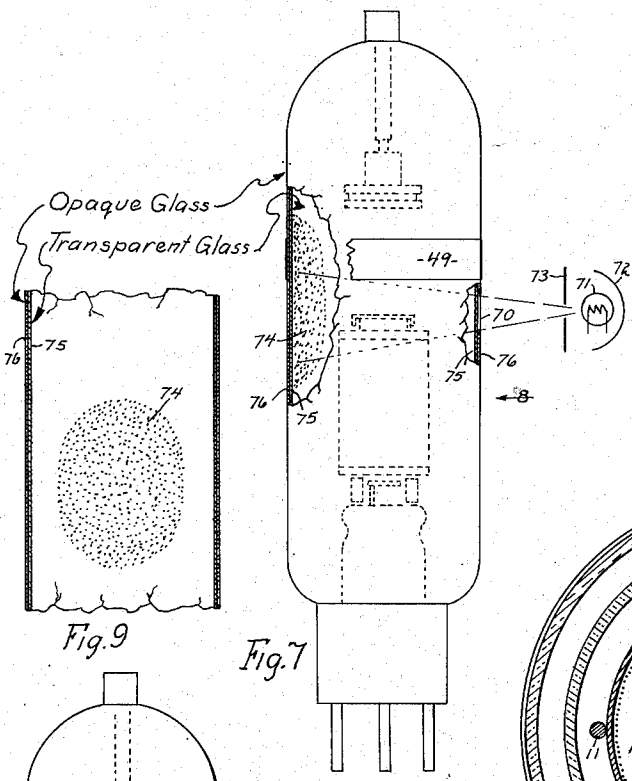



Fig. 7

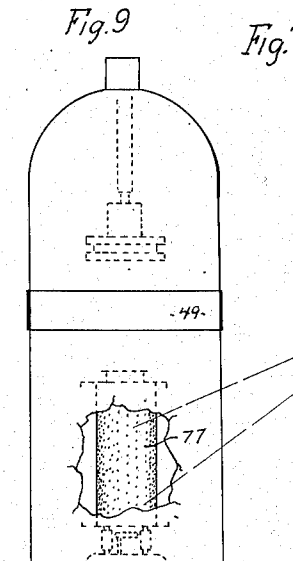



Fig. 9

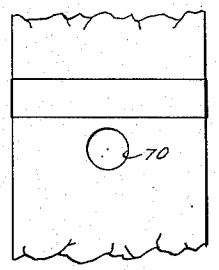



Fig. 8

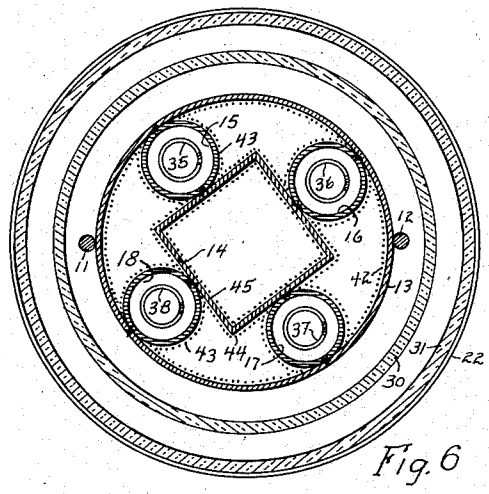



Fig. 6




Fig. 10

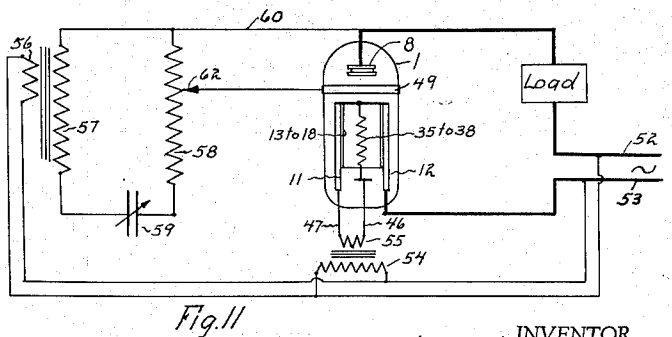



Fig. 11

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Patented Sept. 22, 1942

2,296,269

# UNITED STATES PATENT OFFICE

2,296,269

## PHOTOELECTRIC ELECTRONIC TUBE

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Application May 13, 1940, Serial No. 334,846

14 Claims. (Cl. 250—41.5)

This invention relates to photo-electric electronic tubes.

Heretofore photo-electric electronic tubes have been proposed of two general types. In one type, light sensitive material that is to say, material which when it is exposed to light emits electrons, is provided in an envelope, and the flow of these light-emitted electrons themselves toward a positive electrode in the tube provides the main current through the tube, externally available for use. In the other type, the tube is of the general class of space discharge tubes, and the electrons emitted from the light-sensitive material, start the flow of discharge current through the tube.

In the first type of tube the external current is small because of the low light-effected emission of electrons; and in the second type of tube the external current is small because the current flow producing potential on the main electrodes must be kept to a low value to prevent discharge current from flowing independently of illumination of the light-responsive material.

Because the amount of current made available by such prior tubes when subjected to light is so small, it follows that in most of the practical applications in which light controlled electric power is wanted, the current output of such tubes must be amplified by auxiliary apparatus.

The photo-electric tube of the present invention is per se, a "power tube" of the gaseous discharge type, capable of conducting as much current as such a tube conducts when used as an ordinary power tube, limited in fact only by the maximum permissible temperature rise thereof; and the present invention comprises means by which the current flow between the anode and cathode of such a power tube may be caused to attain its full capacity value, or optionally any fractional part thereof, by the action of corresponding different intensities of light.

The photo-electric tube of the present invention therefore is, in the true sense, a photo-electric power tube, and we therefore designate it and distinguish it from prior photo-electric tubes by the name Photodyne.

While the principle underlying our invention may be variously applied in the photo-electronic art, we have chosen for the purposes of this specification to illustrate and describe it as embodied in a space discharge power tube of the rectifier class, and comprising an envelope containing ionizable gas and an anode and a hot cathode, and having a control electrode or grid. In such as gaseous rectifier tube, discharge current flows only from the cathode to the anode and only when the anode is positive with respect to the cathode; and herein reference to the anode as positive is meant in this sense; also when reference is made herein to energization of the grid with negative potential it is meant in the sense that the grid energization is negative with respect to the cathode anode when the anode is positive with respect to the cathode.

In hot cathode rectifier tubes, a well known construction of cathode comprises, in various forms, metal coated with thermionic material and indirectly heated by an incandescent filament. The electrons emitted by the heated thermionic coating, together with the electrons produced thereby by ionization of the gas in the envelope, and flowing toward the positive anode, constitute the discharge current, (or the path therefor if the current by considered as flowing from the anode as is the conventional fiction). Representative of such thermionic coatings are barium oxide and strontium oxide.

In the well known process of evacuating the envelope of a rectifier tube having such a cathode, the cathode is heated, and some of the thermionic material thereof becomes vaporized and condenses on the inner surface of the envelope in a film of thermionic material, so that in an indirectly heated cathode rectifier when finished, the greater part of the thermionic material remains on the cathode, but a thin film of the same is in the form of a deposit on the envelope wall.

Also at the end of the evacuating process, a so-called getter is employed comprising a metal-enclosed pellet of material, which, upon inductively heating the enclosing metal explodes or flashes into vapor having the property of scavenging the envelope interior by absorbing or chemically uniting with the molecules of gas or water vapor still in the envelope. The getter material then condenses upon the inner wall of the envelope in a thin film. The getter may be located at one end of the envelope, in which case the getter film will form at the corresponding end portion of the envelope. The film consists of metals, and metal oxides, nitrides, carbonates, etc., determined by the getter and the oxygen, nitrogen, carbon dioxide, etc., which may be present in the envelope when the getter is flashed. Representative of such getters is a mixture of 25% barium, 20% aluminum, and 55% magnesium in powdered form.

The ionizable gas in the envelope of such tubes

is introduced after evacuation and representative of such gases is argon.

Now we have discovered that if a hot cathode rectifier of this class when constructed as hereinafter described and evacuated and containing argon (at suitable pressure, to be referred to) and having a film or films on the inner wall of the envelope as described, has its grid energized with a negative potential to the degree which just prevents current flow between the anode and cathode, for a given potential between the anode and cathode, the tube is photo-electric. That is to say, if light falls either upon the thermionic coating of the cathode, or upon the condensed thermionic coating, or upon the condensed getter coating on the envelope inner wall, the grid is thereby rendered ineffective to prevent the current flow; and current flows between the cathode and anode, and furthermore, flows in amount corresponding with the intensity of the light falling on either of the said coatings; and in correspondence with variations of the intensity of the illumination of the coating, the current flow varies, from very small amperage up to and including the maximum amperage capacity of the tube as a rectifier tube; and ceases to flow when the light is interrupted.

And we have found furthermore that if the negative potential of the grid be increased still further and beyond the degree at which it prevents flow as a rectifier, a degree of super energization is reached at which the discharge current again flows; and that if then either of the said coatings be exposed to light, the grid is thereby rendered ineffective to maintain the flow and the current flow is interrupted or is reduced commensurably with the intensity of the light.

The tube of this invention responds to light as stated above, when the grid is inside the envelope, between the cathode and anode, but we prefer to employ an outside band-grid, encircling or embracing the outer wall of the envelope, such band-control electrodes being well known and being described in the patent to Palmer H. Craig, representative of which is Patent No. 2,001,836, issued May 21, 1935.

We are not, at the present time, certain as to the exact nature of the above described phenomenon, or the full explanation thereof. Obviously, the aforesaid response of the tube to light is not dependent upon the use of so-called light-sensitive material, nor in fact upon light-sensitive properties as such, of the coatings within the envelope. The amperage flowing through the tube in response to the action of light, being at its maximum, equal to the discharge amperage capacity of the tube as a rectifier, is many times greater than the electron flow which could possibly be emitted from the said coatings considered as light sensitive coatings, even if such light sensitive coatings were of the maximum possible area that could be contained within the envelope. The phenomenon seems to depend upon the joint action (*a*) of the grid in normally preventing electron flow between the cathode and anode, or in causing it to flow, as the case may be; and (*b*) of the coating in wholly or partially inhibiting the said action of the grid when exposed to light.

The phenomenon may be electro-static in character. When the outside band grid is utilized as described, we believe that it creates an electrostatic charge or field within the envelope, or on the inner wall thereof, the glass wall of the envelope functioning in the nature of the dielectric element of a condenser; and that it is this charge or field produced by the grid which controls the amperage flow through the tube; and that electrons or photons are emitted from the said coatings when subjected to light and that they neutralize or drain off or short circuit the said electro-static charge or field, thus destroying or reducing it (commensurably with the intensity of the light) and correspondingly changing the effect of the grid upon the current flow through the tube. This is evidenced by the fact that the effect of the grid can be varied by diverting or by-passing some of the grid energization by means of a rheostat disposed externally of the envelope and paralleling the grid, as we have found by experiment.

As illustrative of the light responsiveness of tubes embodying the principle above described we have found that a tube having a continuous carrying capacity of 15 amperes, and a capacity of 75 amperes for short periods of time such as thirty seconds, will pass the full 75 amperes, or will cut it off, or will pass any intermediate amount of current in accordance with the intensity of the light to which the tube is subjected.

It is among the objects of this invention therefore:

To provide generally an improved photo-electric tube;

To provide a photo-electric tube responding to the action of light to pass therethrough current of great amperage, limited only by the permissible temperature rise of the tube;

To provide a tube of the rectifier type having a maximum current carrying capacity between the anode and cathode, and rendered responsive in an improved manner to the action of light, to pass current in varying amounts from small currents to said maximum current when illuminated by light in corresponding degrees of intensity;

To provide a photo-electric tube having an improved mode of operation;

To provide an improved construction of rectifier tube of the gas-filled, hot cathode type, adaptable, in an improved manner, to respond to the light as a photo-electric tube.

Other objects will be apparent to those skilled in the art to which our invention appertains.

Our invention is fully disclosed in the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a front elevational view of a tube embodying our invention and with a part of the envelope broken away to disclose internal parts of the tube;

Fig. 2 is a view to enlarged scale partly in longitudinal section of a cathode of the tube of Fig. 1;

Fig. 3 is a view taken from the plane 3—3 of Fig. 2;

Fig. 4 is a view to reduced scale taken in the direction of the arrow 4 of Fig. 2;

Fig. 5 is a view in some respects diagrammatic illustrating the internal construction of the cathode of Fig. 2;

Fig. 6 is a cross-ectional view taken from the plane 6—6 of Fig. 2;

Fig. 7 is a view in general similar to Fig. 1 but illustrating a modification;

Fig. 8 is a fragmentary view taken in the direction of the arrow 8 of Fig. 7, illustrating a part of the envelope of that figure and a window therein;

Fig. 9 is a fragmentary longitudinal sectional view of a part of the envelope of Fig. 7;

Fig. 10 is a view similar to Fig. 1, but illustrating a further modification;

Fig. 11 is a diagrammatic view illustrating an electric circuit system which may be employed with the tubes of Figs. 1, 7 and 10.

Referring to the drawings, we have shown in elevation in Fig. 1, a tube embodying our invention in one form, and comprising a glass envelope 1, having on the lower end thereof a metal plug base 2 of the prong type provided with three insulated prongs, 4, 5 and 6; and having above the base a pinch 7 in which are sealed terminal conductors connected to the prongs. The envelope has been evacuated and contains an ionizable gas such as argon therein at a predetermined pressure to be referred to.

In the upper end portion of the envelope 1 is an anode 8 electrically connected to an external terminal 9 in the usual manner. The anode may be of graphite or molybdenum, or carbon or carbonized nickel, or may be of other materials such as are commonly used for the anodes of tubes of the hot cathode rectifier type.

At 10 is shown generally a cathode of the indirectly heated type. Structurally it comprises, see Fig. 2, a pair of posts 11 and 12, mounted in and extending upwardly from the pinch 7 and spot welded to opposite portions of a main outer cathode cylinder 13 of nickel or other suitable metal. For convenience of assembling, the posts 11 and 12 are in two parts, lower parts 79 and 80 mounted and sealed in the pinch and carrying sleeves 81 and 82 welded thereto, and the upper parts, the posts proper 11 and 12, are telescoped into the sleeves 81 and 82 to mount the posts on the pinch.

Within the cylinder 13 and co-axial therewith is an inner metal tube 14, see Figs. 5 and 6. A plurality of heater tubes 15, 16, 17, and 18 are disposed between the inner wall of the cylinder 13 and the outer wall of the inner tube 14, and spot welded to the tubes 13 and 14 at opposite points on the heater tubes. The cross-sectional form of the inner tube 14 is preferably polygonal, although this is not essential, and it may be of square cross-section as shown, or of hexagonal or octagonal section, and the planar portions of such polygonal tube provide convenient means for positioning the heater tubes 15 to 18 and the outer tube 13 around a common axis of the cathode, as illustrated.

A post 19 mounted in and extending upwardly from the pinch 7 has its upper end disposed in a socket or thimble 20, secured as by welding to a lower outer sheet metal head 21 having an upwardly extending skirt 22 at its periphery. A lower inner sheet metal head 23, likewise provided with a peripheral skirt 24 rests upon the head 21 and is preferably spaced therefrom to reduce heat conduction to the head 21 by means of pimples or bosses 25 pressed outwardly downwardly from the metal of the head 23 and resting upon the head 21.

Perforations are provided in the heads through which the said posts 11 and 12 extend and thereby the heads are positioned relative to the posts. The outer tube 13, inner tube 14, and heater tubes 15 to 18, rest upon the inner head 23 or terminate adjacent thereto, and the head 21 preferably rests upon the upper ends of the sleeves 81 and 82 to further support the heads and tubes.

An upper head 26 is provided having a large central perforation 27 and a downwardly extending periphery skirt 28 secured to the upper end portions of the posts 11 and 12 by tongues 29— 29 bent upwardly from the periphery of the perforation and spot welded to the posts 11 and 12 at their upper ends. The perforation 27 in the upper head is approximately the size of the outer tube 13. Heat insulating tubes or shields 30 and 31 of low heat conducting material, such for example as lava, are provided, resting upon the lower heads 23 and 21 respectively, and axially centered by engaging within the skirts 24 and 22 respectively of the lower heads. At their upper ends the heat insulating shield 31 is engaged within the peripheral skirt 28 of the upper head 26 and the shield 30 is positioned by tongues 32 bent downwardly from the head 26. The inner heat shield 30 is spaced from the tube 13, and the outer shield 31 is spaced from the inner shield thereby providing heat-insulating air spaces therewithin.

Below the cathode proper thus constructed, a ring 33 is supported by being welded to a post 34 mounted in the pinch. Heating filaments 35—36—37—38 of helical form are provided axially of and within the heater tubes 15 to 18, their lower ends being extended axially and spot welded to the ring 33 and their upper ends being extended axially and spot welded to tongues 39 bent upwardly from the upper head 26 at the periphery of the perforation 27.

A heat reflector 40 of nickel or like material and in the form of a disc, is mounted above the cathode proper by tongues 41—41 bent downwardly from opposite edges thereof and spot welded to the upper ends of the post 11 and 12, preferably through the tongues 29.

The reflector reduces radiation axially away from the cathode, and together with the heat insulation effected by the shields 30 and 31 reduces the radiation of heat and enables the filaments 35 to 38 to maintain the desired temperature of the cathode at the expenditure of correspondingly less wattage.

By the construction above described a large sheet metal cathode surface area is provided, and this surface area is covered with a coating of thermionic material such as barium or strontium carbonate or a mixture thereof, which, when the cathode surfaces are heated in the process of evacuating the tube as is customary, is converted into strontium or barium oxide or a mixture thereof. This oxide coating of thermionic material is shown in Fig. 6 at 42, on the inner wall of the outer tube 13 and at 43 on the outer walls of the heating tubes 15 to 18 and at 44 on the outer wall of the inner tube 14 and also at 45 on the inner wall of the tube 14.

An electric circuit to heat the filaments is provided from a wire 46 to the post 34, see Fig. 2, to which is connected the ring 33, thence through all of the filaments 35 to 38 in parallel, to the upper head 26 and thence through the post 11 and out by a wire 47.

A getter such as that referred to is shown at 83, Fig. 1, mounted on a wire 84 welded to a sleeve such as the sleeve 82.

The main circuit through the tube is from the anode connection 9 to the anode 8, through the gap as a discharge arc to the cathode outer tube 13 and thence by post 12 to a wire 48.

The wires 46, 47 and 48, shown best in Fig. 2, are, as will be understood from prior tube practice, connected to the insulated prongs 4, 5 and 6 of the other figures, for example Fig. 1.

The tube as above described may be considered as a rectifier tube having a well known mode of operation which is, that the filaments heat the

said tubes and their thermionic coatings, causing the latter to emit electrons, and these electrons ionize the gas causing it to emit other electrons thereby providing a flow of electrons from the cathode to the anode and when potential is impressed upon the anode and cathode and when the anode is positive; and the electric current being considered, conventionally, as flowing from the anode to the cathode in the nature of a space discharge, and in amount depending upon the external resistance in the circuit.

A grid **49** in the form of an external band-grid upon and outside of the envelope **1** is provided and it may be variously constructed. It may be in the form of a separate metal detachable wire or band of metal; or a band of metal mesh; but preferably we provide a band which in effect is sealed into the material of the outer wall of the envelope. The preferred process for applying such a band-grid, is that used in ornamenting glassware with bands or the like of platinum. A so-called "liquid platinum" is painted in the form of a band on the outer wall of the envelope, and over an outwardly extending nipple **50**. The glass and the band are then heated and the band fuses into the glass surface under the band, having finally the appearance of being a part of the glass. A band thus made is conductive, and a terminal **51** is soldered or otherwise mounted on the nipple by which electric connection can be made to the grid.

The grid is shown as disposed between the cathode and anode, which is its preferred position.

With a tube constructed as above described, and in operation as described, negative energization of the grid at a suitable potential will prevent flow of discharge current through the tube, and lower degrees of energization will permit the flow in inversely corresponding amperage.

When alternating potential is impressed upon the anode and cathode, the flow of current occurs only during those half waves in which the anode is positive, and even without energization of the grid, is automatically interrupted in each half cycle in which the anode is negative; and therefore with alternating current, such a tube admits of control of the effective amperage flowing, by suitable energization of the grid, inasmuch as the grid can at any time be energized to cut off the flow of current by preventing its starting on the next succeeding half cycle; or can control the effective amperage by delaying the time of starting in each positive half cycle. Also if the grid be energized to a degree beyond that at which it completely cuts off or prevents current flow, the current will be caused to flow at such super grid energization, and by reducing or raising this super energization, the effective amperage flow may be conversely increased or decreased or cut off. Because of the greater usefulness of the tube with alternating current as thus indicated, it will be considered herein only in such usage.

A more stable and otherwise satisfactory control of the amperage flowing through the tube may be effected if the alternating voltage impressed upon the grid is out of phase with that impressed upon the anode and cathode. To this end the control of the effective amperage by energization of the grid to delay the start of the current in the positive half cycles may be effected by varying the phase relationship between the grid energization and the potential impressed upon the anode; but we prefer to effect this control by utilizing a fixed angular displacement of the grid energization, and varying the potential on the grid at this phase displacement. We have found that a suitable phase displacement is approximately 135 degrees lag of band grid negative potential behind the anode positive potential.

In Fig. 11 is illustrated a representative circuit for effecting this type of control with a tube such as is described above. In this figure at **1** is shown the envelope, at **8** the anode, at **49** the grid, at **11** and **12** the posts supporting the cathode **13** to **18**, heated by filaments **35** to **38**. Supply mains **52** and **53** energize the primary **54** of a transformer, the secondary **55** of which supplies alternating current at a suitable voltage, such for example as five volts, to the above described heating circuit comprising the wires **46** and **47**. The supply mains also energize the primary **56** of a transformer having a secondary **57** connected in a loop circuit with a resistor **58** and a condenser **59**, the upper end of the resistor **58** being connected to the supply main **52** by a wire **60**. If desired as an alternative arrangement, the lower end of the resistor **58** may be connected to the supply main **53**. The grid **49** is connected at **62** to the resistor **48** by an adjustable rheostat type of connection to adjust the potential on the grid **49**, the circuit for the grid being considered as from the connection **62** to the grid, thence back to a part of the resistor **58**. The condenser **59** may be adjusted to cause the potential on the grid **49** to be out of phase with the potential on the anode **8** as described and at this fixed phase displacement, which as stated above, is preferably of the order of 135 degrees behind the anode potential, the actual potential on the grid **49** may be adjusted by the adjustable connection **62**.

For a rectifier as described above having a continuous main current capacity of 2½ amperes, the capacity of the condenser **59** may suitably be .019 micro-farad, and the resistance of the resistor may suitably be of the order of 150,000 ohms, and the voltage across the resistor, provided by the transformer secondary **57**, may suitably be 600 volts for supply mains at 110 volts, 60 cycles. As stated above, with the fixed phase displacement referred to, the grid connection at **62** may be adjusted from zero potential at which the full 2½ amperes will flow in the main load circuit from the anode to the cathode of the tube, and if the potential on the grid **49** be adjusted to raise it, the effective amperage in the load circuit will be decreased; and at approximately 450 volts on the grid **49**, the main current will be completely cut off; and if the potential on the grid **49** be adjusted to raise it to a super potential above the cut-off value, the current will again flow, and the effective amperage will be greater for higher grid voltage and vice versa. It follows that the effective current supplied to the load of Fig. 6 can be adjustably varied from zero to the maximum capacity of the tube by adjusting the connection at **62**.

The above description is directed to the construction and operation of the tube of Fig. 1, considered as a rectifier tube of the indirectly heated thermionic cathode type. As referred to hereinbefore, when the envelope is evacuated by the usual process which we may employ, some of the heated thermionic coating is evaporated and deposited on the inner surface of the envelope in a thin film, and the getter when flashed also deposits a film on the tube wall. A film is indicated in Fig. 1 by the dotted line **63**, and this may be considered as the thermionic film, or the getter film, or both.

The photo-electric property of the tube, to which this specification is particularly directed, is brought into action by two methods. The first method is by energizing the grid **49** with a negative potential preferably out of phase with the potential impressed upon the anode and cathode as described and preferably just sufficient to prevent the flow of discharge current as described; so that considered as a rectifier tube, the tube is normally in the condition to prevent current flow. If now, light is caused to illuminate either the thermionic coating on the cathode or the film **63** on the inner wall of the envelope (whether it be the part composed of thermionic material or the part deposited by the getter or both) the inhibiting action of the grid is in itself inhibited, and the tube passes current between the anode and cathode. The amount of the current which thus flows is directly commensurable with the degree of intensity of illumination of the thermionic material, or of the film, and if the illumination be sufficiently intense, the tube will pass amperage of current up to its full capacity, depending upon the resistance of the external load circuit, and if the illumination is decreased the amperage flowing through the tube decreases commensurably therewith, and if the illumination is entirely removed the current again ceases to flow.

In the second method of bringing into action the photo-electric property of the tube, the grid **49** is energized with a super negative potential, high enough to be beyond the potential at which current flow is prevented, and at this super potential current normally flows through the tube, the greater the super potential the greater the current and vice versa. The grid is therefore adjusted to a super potential at which the maximum current that is wanted will normally flow, this maximum having of course a top limit at the discharge capacity of the tube. If now light is caused to illumine either of the three coatings referred to, or several of them, the action of the grid in causing the maximum current flow is thereby inhibited and the current flow is cut off or is reduced inversely commensurably with the degree of intensity of the illumination.

As will now be apparent, by the aforesaid first method of operation, the discharge current amperage increases from zero to higher values (up to the full discharge capacity of the tube) with increasing intensity of light, the flow of current being directly commensurable with the light; and by the aforesaid second method of operation the discharge current decreases from a high value (a value determined by the degree of super grid energization) down to zero with increasing intensities of light, the flow of current being inversely commensurable with light.

So far as we are aware in no prior photo-electric tube does the current vary inversely with light intensity.

We have found that the response of the tube to light is sensitive, and that the light from an ordinary 50 watt commercial lamp at a distance of several feet from the tube and directed upon the tube by a reflector is sufficient to cause the tube to respond and pass (or cut off, as the case may be) its full capacity of current.

In Fig. 1, we have shown at **64** a source of light directed by a reflector **65** upon the coating of the cathode **10**, through a shutter **66**, by which shutter the intensity of the incident illumination may be controlled; and at **67**, **68** and **69**, we have shown a similar arrangement of light source, reflector and shutter for variably illuminating the film **63**.

The tube as illustrated in Fig. 1, has an envelope all of which is transparent to light. In some uses it may be desirable to install the tube in a location in which it is at all times exposed to light, such as daylight or that of illuminating lamps. In such cases, we prefer to employ an envelope such as that shown in Fig. 7. This envelope is opaque except for a small transparent window **70**, and the controlling light is provided by a lamp **71**, reflector **72** and shutter **73** directing a pencil of light toward and through the window which pencil of light may be modified or interrupted by movement of the shutter. The pencil of light passing through the window falls upon a film **74** provided on the inner wall of the envelope, the film, as will be apparent, receiving no light except that of the pencil. In this figure, we have illustrated for the film **74**, a coating of predetermined area and shape, which has been deposited upon the inner wall of the envelope intentionally by distillation or other well known process, and disposed opposite the transparent window in alignment therewith and with the pencil of light.

The envelope of this figure may be rendered opaque by any suitable process, but we prefer to make the envelope initially of transparent glass, as at **75**, and then to superimpose thereon a layer of opaque glass, as at **76**, fused to the underlying transparent layer, leaving uncoated the transparent window **70**. The film **74** is disposed so that the minimum of shadow will be thrown thereon by the parts within the envelope which lie in the path of the ray of light entering the window.

As an alternative arrangement, the envelope may be made of transparent glass and covered inside with lamp black or other opaque material except for uncovered portions for the window and the coating.

In Fig. 10, we have shown a modification which may be incorporated into the form of Fig. 1, or of Fig. 7. Here, the heat shields **30** and **31** of the form of Fig. 1, have been omitted, and the exterior surface of the cathode tube **13** is also coated with thermionic material, as at **77**, Fig. 10, and functions in the operation of the tube as a rectifier, and the ray of light to operate the tube photo-electrically is directed upon this coating, as illustrated, under the control of a shutter **78**.

As mentioned hereinbefore, rectifier tubes of the gaseous discharge type are known containing a gas such as argon in the envelope. In the above described tube, we also prefer to employ, as stated, a gas such as argon, but we have found that the pressure of the gas within the envelope when the tube is to be used for its light responsive properties described must be taken into account. For any pressure utilized, the grid energization should correspond if the optimum photo-electric effect is wanted. If a low gas pressure is used, the grid voltage used to normally prevent current flow may be and should be lower and vice versa. At the higher gas pressures and corresponding higher grid voltage as well as at the lower pressures and corresponding lower grid voltage, the above described photo-electric action is present, but for a given maximum light intensity the maximum flow of current decreases as the pressure and grid voltage increase and also as they decrease. It follows that there is an intermediate optimum pressure (and corresponding grid voltage) and we have found that for argon gas, which we prefer to use, this optimum

pressure is of the order of 10 to 200 microns of mercury.

In the foregoing we have referred to the photoelectric property of the tube as being put into effect according to the first method, by energizing the grid negatively at a potential which just prevents main current flow. This is the preferred condition when it is desired that the main current flow is to be cut off entirely by cutting off the illumination. We have found that if the grid be energized sufficiently to permit a reduced or minimum main current flow through the tube, then, in response to the action of light, the tube will pass more current than this minimum, when illuminated as described; and if the illumination be removed, the current will drop back to the said minimum value, and our invention contemplates the control of the main current in this manner. Likewise in the second method of operation our invention contemplates a super grid energization which, in the absence of illumination, will cause the tube to pass a desired maximum current.

We have referred hereinbefore to shutters to control the intensity of the illumination of the tube, and such shutters are representative of objects of any kind which may be moved into position to intercept or change the intensity of the illumination, whereby the main current flow through the tube will be controlled by such moving objects, or by the presence or absence of any light intercepting object.

In alternating current installations, in which variation in the flow of current through the tube in response to variations of light intensity is not wanted, and all that is wanted is initiation and interruption of current responsive to light, the negative grid may be energized in phase with the positive anode.

Also, while we have described the control of variation of the current flow through the tube in response to variations of light intensity by utilizing a negative grid energized out of phase with the positive anode and having the grid potential adjusted by a rheostat, it is to be understood that our invention may likewise be practiced by a system which adjusts the phase displacement of the grid energization with respect to the anode potential.

It is believed that these alternative methods of practicing our invention will be understood from the more complete description of the preferred method without further illustration or description herein.

As referred to hereinbefore, the tube illustrated and described herein, apart from its photoelectric property, is a tube of the rectifier class, the amperage of the discharge through which may be controlled and varied by controlling the grid voltage (or its phase relation to the anode voltage).

The tube of this application considered as a rectifier tube constitutes the subject matter of the copending application of Palmer H. Craig and John J. Glauber, filed May 31, 1940, Serial Number 338,194, assigned to the same assignee as the present application.

Our invention is not limited to the exact details of construction illustrated and described nor to the exact means of rendering the tube responsive to the action of light. Changes and modifications may be made within the scope of our invention without sacrificing its advantages and within the scope of the appended claims. For example, the tube of our invention may be used in multiple "back-to-back" arrangemen , to pass a full wave of alternating current.

We claim:

1. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential of a value sufficient to cause discharge current to flow in the tube and circuit but normally preventing current flow by energization of the control electrode, causing discharge current to flow by subjecting the light-responsive material to light and determining the amperage of the current by the intensity of the light, independently of the value of said electrical potential.

2. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube enxelope, which includes subjecting the anode and cathode to electrical potential of a value sufficient to cause discharge current to flow in the tube and circuit but normally preventing current flow by energization of the control electrode, and causing discharge current to be initiated and attain a preselected amperage independently of the value of said electrical potential, by subjecting the light-responsive material to light at a corresponding preselected intensity.

3. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential sufficient to cause discharge current to flow in the tube and circuit but normally preventing current flow by energization of the control electrode, causing discharge current to flow by subjecting the light-responsive material to light, and causing the current to vary by varying the intensity of the light.

4. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential sufficient to cause a normal value of discharge current to flow while concurrently energizing the control electrode to maintain the current flow in the circuit at a lower value less than the normal value, and causing the lower value to change by subjecting the light-responsive material to light.

5. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential sufficient to cause a normal value of discharge current to flow while concurrently energizing the control electrode to maintain the current flow in the circuit at a lower value less than the normal value, and causing the lower value to

increase by subjecting the light-responsive material to light.

6. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential sufficient to cause a normal value of discharge current to flow while concurrently energizing the control electrode to maintain the current flow in the circuit at a lower value less than the normal value, and causing the lower value to increase by subjecting the light-responsive material to light, and limiting the amperage of the increased value by limiting the intensity of the light.

7. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential sufficient to cause a normal value of discharge current to flow while concurrently energizing the control electrode to maintain the current flow in the circuit at a lower value less than the normal value, and causing the lower value to vary by subjecting the light-responsive material to light of varying intensity.

8. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential sufficient to cause a normal value of discharge current to flow while concurrently energizing the control electrode to maintain the current flow in the circuit at a lower value less than the normal value, and causing the lower value to increase and attain a preselected amperage by subjecting the light-responsive material to light at a corresponding preselected intensity.

9. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier type space discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes: subjecting the anode and cathode to electrical potential sufficient to cause a normal discharge current to flow while concurrently energizing the control electrode to a greater degree than that which would be sufficient to prevent current flow and thereby causing current to flow at a lower value less than the normal value; and causing the lower value to decrease by subjecting the light-responsive material to light.

10. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier type space discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes: subjecting the anode and cathode to electrical potential sufficient to cause a normal discharge current to flow while concurrently energizing the control electrode to a greater degree than that which would be sufficient to prevent current flow and thereby causing current to flow at a value less than the normal value; and causing the discharge current flow to cease by subjecting the light-responsive material to light.

11. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier type space discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes: subjecting the anode and cathode to electrical potential sufficient to cause a normal discharge current to flow while concurrently energizing the control electrode to a greater degree than that which would be sufficient to prevent current flow and thereby causing current to flow at a lower value less than the normal value; and causing the lower value to decrease to a preselected value by subjecting the light-responsive material to light at a corresponding preselected intensity.

12. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier type space discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes: subjecting the anode and cathode to electrical potential sufficient to cause a normal discharge current to flow while concurrently energizing the control electrode to a greater degree than that which would be sufficient to prevent current flow and thereby causing current to flow at a lower value less than the normal value; and causing the lower value to vary by subjecting the light-responsive material to light of varying intensity.

13. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope, which includes subjecting the anode and cathode to electrical potential sufficient to cause a normal value of discharge current to flow in the tube and circuit while concurrently preventing the current flow from attaining the normal value by energization of the control electrode, and subjecting the light-responsive material to light to cause a flow of discharge current directly commensurable with the intensity of the light.

14. The method of controlling the current amperage in an electric circuit having connected therein the anode and cathode of a rectifier-type space-discharge electronic tube comprising a control electrode and containing light-responsive material in the tube envelope which includes: subjecting the anode and cathode to electrical potential sufficient to cause a normal value of discharge current to flow in the tube and circuit while concurrently preventing the current flow from attaining the normal value by energization of the control electrode and subjecting the light responsive material to light to cause a flow of discharge current inversely commensurable with the intensity of the light.

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