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A. M. SKELLETT

2,244,318

ELECTRON DISCHARGE DEVICE

Filed Dec. 31, 1937

FIG. 1

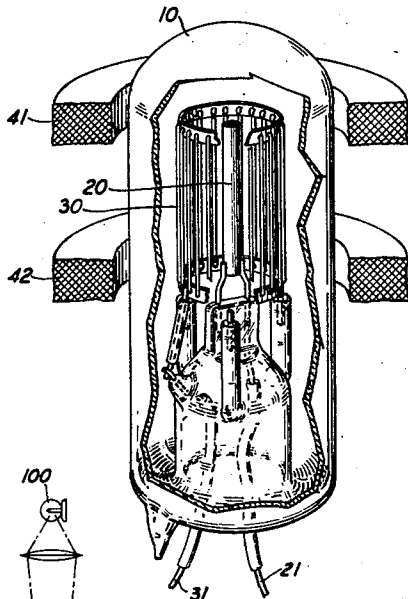


FIG. 2

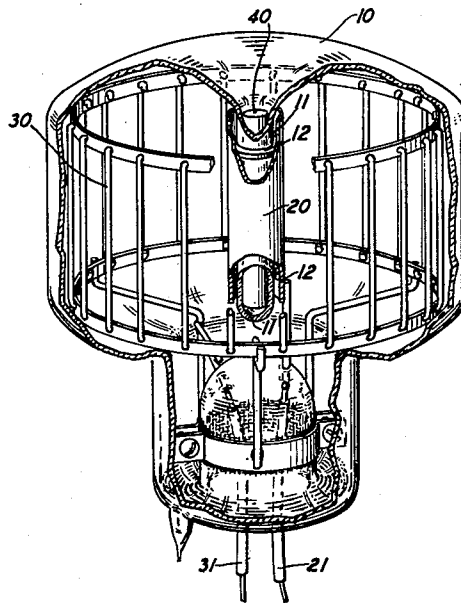


FIG. 3

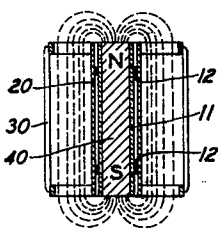


FIG. 4

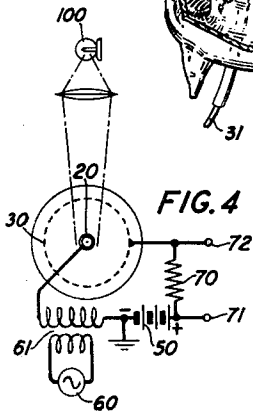


FIG. 5

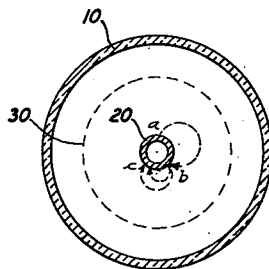


FIG. 6

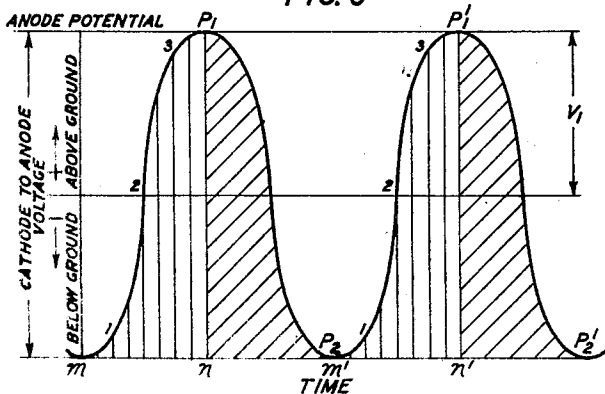


FIG. 7

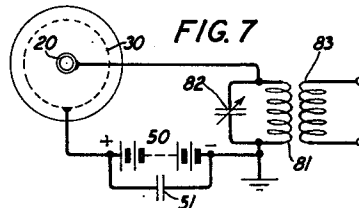
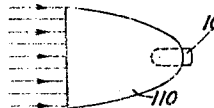


FIG. 8



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ELECTRON DISCHARGE DEVICE

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11 Claims. (Cl. 250-27)

This invention relates to electron discharge devices utilizing secondary electron emission and more particularly to such devices in which repeated electron multiplication is obtained by secondary electron emission from the same cathode.

An object of this invention is to provide an improved electron discharge device wherein electron multiplication takes place by repeatedly and successively causing electrons to bombard a cathode, capable of emitting secondary electrons, with sufficient force to cause increased emissions by the impacts.

Another object is to provide an improved photoelectric tube in which the photoelectric current is amplified by the cathode of the tube emitting secondary electrons due to successive electron bombardment of the same cathode.

A further object is to provide an improved oscillation generator in which the cathode of an electron discharge device successively emits secondary electrons.

An electron discharge device illustrative of this invention utilizes secondary electron emission in such a way that electrons emitted from the convex surface of a hollow cylindrical cathode travel in looped paths and return to the cathode to cause increased emission by bombardment. The control is both electrostatic and magnetic. One form of the device comprises a cylindrical photoelectric cathode surrounded by a coaxial grid type anode within an evacuated container or vessel. Means such as a permanent bar magnet located inside of the cathode or solenoid windings positioned exteriorly to the container produce a magnetic field in the space between the cathode and the anode with the lines of force, substantially parallel to the axis, common to the electrodes. This magnetic field causes the electrons to traverse curved paths and return to the cathode under suitable cathode to anode voltages. When a cyclically pulsating voltage of suitable frequency is impressed between the cathode and the anode, multiplication by repeated bombardment takes place during the part of the cycle in which the cathode becomes less and less negative with respect to the anode, and during the other part of the cycle in which the cathode becomes more and more negative with respect to the anode the electrons are collected at the anode. The cathode is an emitter of both photoelectric and secondary electrons.

This device with the central cylindrical cathode surrounded by the open mesh anode and means for producing the magnetic field designed

so as not to interfere with the illumination of the cathode may be operated as an electron multiplier photoelectric tube, and also as a high frequency oscillator either modulated by light or independently of light. In the latter case the cathode need only to be so constructed as to be a good secondary emitter of electrons independently of its photoelectric sensitivity.

A more detailed description of the invention follows:

Fig. 1 is a perspective side and partial sectional view of an electron discharge device employing solenoid windings for producing a magnetic field;

Fig. 2 is a perspective side and partial sectional view of an electron discharge device employing a permanent magnet for producing a magnetic field;

Fig. 3 is a longitudinal sectional view of the electrodes and the permanent magnet of the arrangement shown in Fig. 2;

Fig. 4 is a circuit arrangement of the electron discharge device operating as a photoelectric tube;

Fig. 5 shows diagrammatically the path of an electron shot out of and returned to the cathode and paths of resulting secondary electrons;

Fig. 6 is a graph showing the action of the electron discharge device during two cycles of operation;

Fig. 7 is a circuit arrangement of the electron discharge device operating as an oscillator; and

Fig. 8 shows the electron discharge device equipped with a parabolic reflector for concentrating light rays on the cathode.

Similar reference characters refer to corresponding parts in the different figures of the drawing.

Fig. 1 shows a perspective side and partial sectional view of the electron discharge device employing solenoid windings for producing the magnetic field. A container or envelope 10 of any suitable material such as glass, from which the gas has been highly exhausted, contains the electrodes and their supports. The electron emitting cathode 20 in the form of a small hollow cylinder is centrally mounted within the container 10. The cylindrical anode 30 is coaxially mounted around the cathode and so formed as to permit light to reach the cathode from substantially all directions. Suitable lead-in wires 21 and 31 are sealed to the stem of the container and connect with the electrodes 20 and 30, respectively. The cathode 20 is made of material to readily and efficiently emit electrons when exposed to light and also when

bombarded by other electrons to amply emit secondary electrons. It may be of silver coated with the usual caesium-oxide silver surface and is here shown in the form of a small elongated hollow cylinder with a relatively thin wall. The anode 30 is made of any suitable conducting but non-magnetic material such as copper, aluminum or the like and may be fabricated in open mesh grid design in the form of a squirrel cage as shown in the drawing, or with wire mesh, or as a latticed cylinder, the design being such as to have a large amount of open space for permitting the light to pass within to the concentrically positioned cathode 20. Both the cathode 20 and the anode 30 preferably employ a relatively small amount of material so as to reduce to a minimum the problem of removing the occluded gas. A uniform magnetic field with the lines of force substantially parallel with the axis of the electrodes is produced by means of spaced solenoid coils 41 and 42. The coils are of such size and so spaced as to readily permit light flux to reach the cathode 20 from all radial directions.

An electron discharge device constructed substantially as shown in Fig. 1 and tested in actual operation comprised a thin light sensitive tubular cathode approximately one-eighth inch in diameter and one and one-half inches long concentrically surrounded by a "squirrel cage" shaped anode one inch in diameter and one and five-eighths inches long. The evacuated glass container in which the electrodes were mounted was approximately two inches in diameter and four and one-half inches long. Other dimensions, however, may be employed.

Fig. 2 shows a perspective side and partial sectional view of an electron discharge device which is similar to Fig. 1 with the exception that the magnetic field is produced by a permanent magnet instead of by solenoid windings. While the permanent magnet 40 might be positioned within the evacuated chamber and inside of the cylindrical cathode 20 of the structure shown in Fig. 1, it is preferable to modify the containing vessel 10 by adding an exteriorly opening and internally extending tubular reentrant stem 11 around which, but spaced therefrom by mica spacer washers 12, the cathode 20 is positioned within the container and in which the permanent magnet 40 is positioned in the exteriorly open portion of the reentrant stem. This permits the initial insertion or the replacement of the permanent magnet at any time and also obviates the removal of occluded gas in the permanent magnet which would be necessary were the permanent magnet placed in the cathode during construction in the arrangement shown in Fig. 1.

Fig. 3 shows more in detail the relative positions of electrodes 20 and 30 and the permanent magnet 40 of the arrangement shown in Fig. 2, drawn to a different scale, and especially the direction of the magnetic lines of force shown by the dashed lines. The portion of the reentrant stem 11 surrounding the magnet 40 and the spacer washers 12 between the stem 11 and the cathode 20 are also shown. The magnetic lines of force occupy the space between the two electrodes and the direction of the lines of force is substantially perpendicular to the radii of the cathode. With the magnetic lines of force having such direction, electrons shot out from the cathode toward the anode must transversely cross the lines of force. The lines of force so po-

sitioned consequently tend to bend the electrons back toward the cathode over looped paths as diagrammatically shown in Fig. 5. Positioning the open mesh cylindrical anode 30 concentrically with the cylindrical cathode 20 has an advantage over the reverse arrangement in which the anode is positioned in the center in that the light can be directed from all sides of the tube, and higher frequencies can be developed because the electrons do not travel through regions of equipotential electric force.

Fig. 4 shows a circuit arranged for operating the electron discharge device of either Fig. 1 or Fig. 2 as a photoelectric tube employing secondary electron emission to increase the output. A source of alternating current 50 impresses through the transformer 61 a sine or other suitably shaped wave upon the circuit to cause proper potential variation of the cathode 20 with respect to the anode 30 to cause electron multiplication. The anode 30 is maintained at a high positive potential above ground by the direct current source 50. A load impedance 70 completes the output circuit, and connections 71 and 72 across this impedance provide means for taking off the amplified signal variations controlled by the light flux from any suitable source 100 exciting the cathode. A steady magnetic field of proper strength is provided either by solenoid windings or by a permanent magnet whose lines of force are substantially parallel with the common axis of the electrodes.

The probable way in which the circuit of Fig. 4 functions, is that the primary electrons, initially photoelectrically produced by illumination of the cathode 20, first loop back toward the cathode during the interval when the cathode is becoming less and less negative with respect to the anode, so that they strike the cathode with sufficient force to emit secondary electrons. These secondary electrons, which are more numerous than the primary electrons which produce them, follow a similar cycle looping back to the cathode under the combined electric and magnetic fields to repeatedly strike it and cause the emission of still greater numbers of secondary electrons. This multiplying action goes on until the potential of the cathode no longer approaches that of the anode during the flight of the electrons over the looped paths, namely, until the sine wave passes its crest and the cathode begins to go increasingly negative with respect to the anode. During this second half cycle the electrons spiral out to the anode where they are collected. In other words the high frequency alternating potential wave of proper value impressed across the electrodes of the tube causes during each alternate half cycle electron multiplication to repeatedly take place by impact of the electrons against the cathode, and during the other alternate half cycle permits electrons to be collected by the positively charged anode. On the multiplication half cycle while the electrons complete one loop back to the cathode, the cathode changes potential with respect to the anode enough so that the electrons strike it with 50 to 100 volts energy to cause their multiplication. On the collection half cycle the electrons spiral over to the anode and are collected, as stated above.

The above described probable functioning of the circuit of Fig. 4 will now be described in more detail by reference to Figs. 5 and 6.

Fig. 5 diagrammatically shows the looped paths of a primary electron and those of the secondary

electrons after their generation. As heretofore stated, the magnetic lines of force set up in the space between the electrodes 20 and 30, by either the solenoid windings or the permanent magnet, as illustrated in Fig. 3, tend to cause the electrons emitted from the cathode 20 to return to it over looped paths as diagrammatically shown in Fig. 5. An electron emitted from the cathode at *a* forcefully returns over a looped path at *b* and causes the emission of secondary electrons which likewise return over looped paths to bombard the cathode at *c* and cause the emission of more secondary electrons. Many such actions are going on at each instant during the generation of secondary electrons. The magnetic field and the electrostatic field operates on both the primary and the secondary electrons to cause them to return to the cathode.

Fig. 6 shows the potential variations of the cathode with respect to the anode as following a sine wave. A steady positive potential V_1 from a source 50 applied between the cathode and the anode holds the anode at a high positive potential V_1 and a superimposed alternating potential having a peak amplitude about equal to the steady potential V_1 from a source 60 causes potential variations of the cathode with respect to the anode over a range of about twice the steady potential V_1 . At the point P_1 on the curve, the cathode and the anode are at nearly the same potential, while at the point P_2 the cathode is negative with respect to the anode by about twice the steady potential V_1 . During a part of each cycle as shown by the vertically shaded portions of this curve, electron multiplication is taking place and during the other part as shown by the obliquely shaded portions the multiplied electrons are drawn to and collected by the anode. The movement of the electrons during multiplication follows looped paths from and back to the cathode somewhat as shown in Fig. 5, and during collection by the anode the electrons spiral out to it.

As shown in Fig. 5, an electron emitted from the cathode 20 at *a* will strike at *b* causing the release of more than one secondary electron. These secondary electrons will go on to *c*, etc., thus greatly multiplying or amplifying the output current. As the cathode becomes less and less negative with respect to the anode during the time from *m* to *n*, as shown by the curve of Fig. 6, multiplication is taking place. The voltages of the cathode corresponding to points *a*, *b*, *c*, etc., may be considered as shown by points 1, 2, 3, etc. on the curve. During the multiplication half cycle from *m* to *n* the electrons start out over looped paths and when they get back to the cathode, its voltage has become more positive and consequently the electrons hit the cathode with energy equal to the difference between the cathode potential at the time they left it and that obtaining when the electrons strike it again. This potential difference must be at least equal to that necessary to cause the secondary to primary electron generation ratio to be greater than 1. This continues throughout the multiplication half cycle, the loops getting smaller and smaller because of the decreasing voltage difference produced by the superimposed alternating potential wave until finally when the potential of the cathode is about the same as that of the anode, the electrons will cease to return to the cathode, and will then start to spiral out to be collected by the anode, this collection taking place during the period *n* to *m'* of increasing

potential difference until the maximum is again reached and the cycle starts over again.

Fig. 7 is a circuit arranged for operating the electron discharge device as an oscillation generator. The cathode 20, a good emitter of secondary electrons, and the anode 30 are connected by an external circuit including a tuned circuit consisting of an inductance 31 and a variable capacitance 32 in shunt and a steady source of high potential 50 having its positive side connected with the anode 30. The source of potential 50 is preferably shunted by a capacitance 51. Output connections with the oscillator circuit may be obtained through the transformer action on winding 33 positioned in inductive relationship with the inductance 31 of the tuned circuit. As heretofore stated, when the electron discharge device is operating as an oscillator the cathode need not be light sensitive, but must be a good emitter of secondary electrons. However, its output may be modulated by light by employing a light sensitive cathode or electrically by well-known circuit connections. Operation of the oscillator may be initiated by causing a sharp electric disturbance in the circuit. Such a shock may be accomplished in a number of ways such as by quickly opening and closing the primary oscillating circuit. In this discharge device higher frequencies can be developed as the electrons do not travel through equipotential electric fields of force. This oscillator is of very simple construction and is capable of oscillating over a very wide band of frequencies.

Fig. 8 shows the electron discharge device equipped with a parabolic or other suitable reflector for concentrating the light rays on the cathode of the tube. The reflector 110 and the tube 10 are so positioned that the cathode of the discharge device is positioned in the focus of the reflector. The parabolic reflector may be either circular with its axis and that of the cathode of the tube coinciding as shown in Fig. 8, or the parabolic mirror may be cylindrical with its axis and that of the cathode of the tube also coinciding. Such a reflector has the advantage of concentrating the light flux around the cathode.

What is claimed is:

1. An electron discharge device comprising an evacuated container, a cylindrical cathode the convex surface of which is capable of emitting secondary electrons, a cylindrically shaped electrode surrounding and coaxial with said cathode, means for producing a magnetic field in the space between said cathode and electrode substantially parallel to the axis of said cathode, and means to apply a pulsating potential between said cathode and electrode of such value and frequency that some of the electrons emitted from said cathode return to said cathode with sufficient energy to cause the emission of additional secondary electrons.

2. An electron discharge device comprising an evacuated container, a cylindrical cathode having a convex surface capable of emitting secondary electrons, a cylindrically shaped electrode surrounding and coaxial with said cathode, a permanent magnet concentrically positioned within said cylindrical cathode for producing a magnetic field in the space between said cathode and electrode substantially parallel to the axis of said cathode, and means for applying a pulsating potential between said cathode and electrode of such value and frequency that some of the electrons emitted from said cathode return to said cathode with sufficient energy to cause

the emission of additional secondary electrons.

3. An electron discharge device comprising an evacuated container, a cylindrical cathode the convex surface of which is capable of emitting secondary electrons, a cylindrically shaped electrode surrounding and coaxial with said cathode, spaced solenoid windings for producing a magnetic field in the space between said cathode and electrode substantially parallel to the axis of said cathode and arranged to freely admit light to said cathode, and means to apply a pulsating potential between said cathode and said electrode of such value and frequency that some of the electrons emitted from said cathode return to said cathode with sufficient energy to cause the emission of additional secondary electrons.

4. An amplifying photoelectric system comprising an electron discharge device including a cylindrical cathode having a convex light sensitive surface capable of emitting secondary electrons, a cylindrical grid-like anode coaxially surrounding said cathode, and an evacuated container enclosing said cathode and said anode, means for producing a magnetic field in the space between said cathode and said anode with the lines of force substantially parallel to the axis of said cathode, an external circuit connecting across said cathode and said anode and including an output impedance, a source of steady potential, and a source of alternating potential, and output circuit connections leading from said circuit.

5. A high frequency oscillation generator comprising an electron discharge device including a cylindrical cathode having a convex surface capable of emitting electrons, a cylindrical anode coaxially surrounding and having openings permitting light to impinge upon the convex surface of said cathode, and an evacuated container enclosing said cathode and said anode, means for producing a magnetic field in the space between said anode and said cathode with the lines of force substantially parallel to the axis of said cathode, an external circuit connecting across said cathode and said anode and including a tuned network and a source of steady potential maintaining a difference in potential between said cathode and said anode, and an output circuit coupled with said external circuit.

6. An electron discharge device comprising an evacuated container, an elongated cathode which is capable of emitting secondary electrons, an elongated anode spaced from and generally parallel to said cathode, means for producing a magnetic field in the space between said cathode and said anode with lines of force substantially parallel to the axis of said cathode, and means for applying a pulsating potential between said cathode and said anode of such value and frequency that some of the electrons emitted from said cathode return to said cathode with sufficient energy to cause the emission of additional secondary electrons.

7. An electron discharge device for causing repeated electron multiplication from the same cathode, comprising an elongated cathode electrode capable of emitting secondary electrons, an anode electrode encircling said cathode, means for producing a steady magnetic field in the space between said electrodes with the lines of magnetic force substantially paralleling the axes of said electrodes, means for producing an electrostatic field between said electrodes, and

means for cyclically varying said electrostatic field over such a range of intensities that electrons emitted from said cathode return thereto with sufficient energy to cause repeated electron multiplication during one part of each of said cycles and to cause the electrons to collect on the said anode during another part of each of said cycles.

8. An electron discharge device comprising an evacuated container, a single cylindrical cathode having a convex surface capable of emitting secondary electrons, a single cylindrically shaped electrode surrounding and coaxial with said cathode, and a permanent magnet concentrically positioned within said cylindrical cathode for producing a magnetic field in the space between said cathode and said electrode with the lines of force substantially parallel to the axis of said cathode.

9. A photoelectric tube comprising a hollow cylindrical cathode having an electrically coextensive convex surface capable of emitting secondary electrons, an anode coaxially surrounding said cathode and having an electrically coextensive surface, an evacuated container enclosing said cathode and said anode, and a magnet positioned within the said cathode and producing a magnetic field in the space between said anode and said cathode with the lines of force substantially parallel to the axis of said cathode.

10. A photoelectron multiplying device comprising a photosensitive cathode capable of emitting primary electrons when excited by radiant energy and capable of emitting secondary electrons when bombarded by electrons, an electrode spaced from said cathode, means for producing a magnetic field between said cathode and said electrode having lines of force generally parallel to the surface of said cathode, means including said magnetic field for bombarding said cathode by said primary electrons with sufficient force to cause emission of secondary electrons and said secondary electrons in turn to successively bombard the same cathode thereby producing more secondary electrons, and means including said cathode and said electrode for impressing a varying electrostatic field between said cathode and said electrode with its lines of force generally normal to those of said magnetic field.

11. An electron discharge system comprising a single cathode capable of emitting primary and secondary electrons, a single electrode coaxially positioned with reference to said cathode, an evacuated container enclosing said cathode and said electrode, means for producing a magnetic field in the space between said cathode and said electrode with the lines of force substantially parallel to the axis of said cathode, means for maintaining all of the surface of said electron emitting element at any instant at substantially the same electrical potential and polarity with reference to that of said electrode, means for producing and for cyclically applying a varying potential between said cathode and said electrode for causing some of the electrons emitted from said cathode to return thereto with sufficient energy to cause the emission of additional secondary electrons during one part of each of said cycles and to cause the electrons to collect on said electrode during another part of each of said cycles.

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