July 16, 1940. S. B. INGRAM 2,208,129

PHOTOELECTRIC TUBE

Filed Dec. 21, 1937

FIG. 1

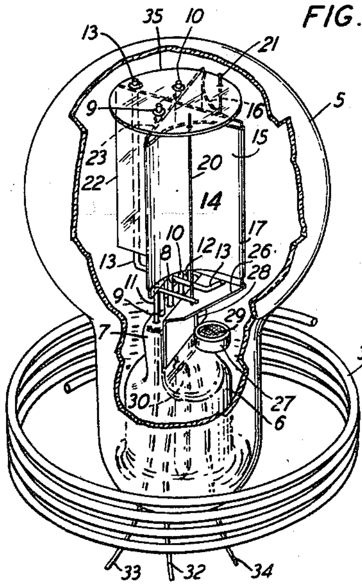


FIG. 5

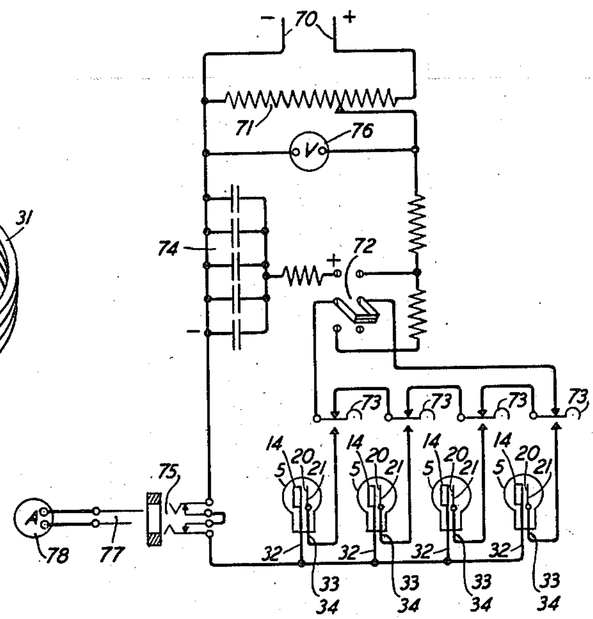


FIG. 2

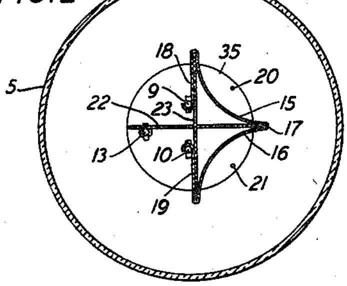


FIG. 3

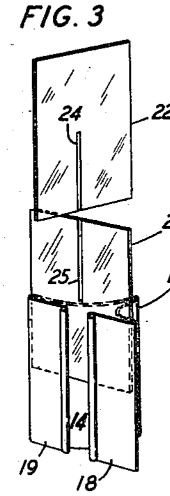
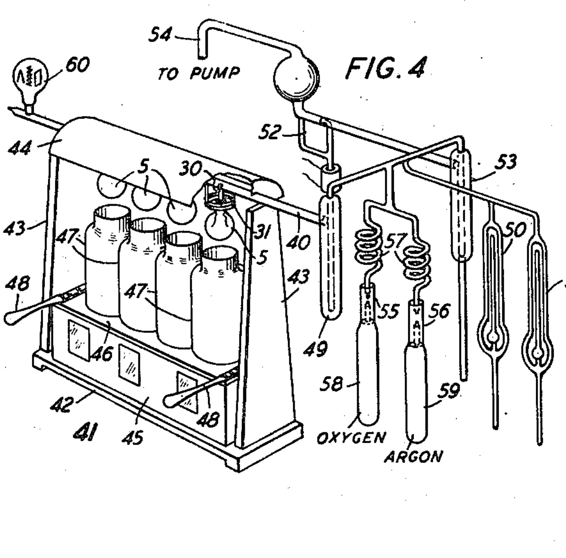


FIG. 4

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# UNITED STATES PATENT OFFICE

2,208,129

## PHOTOELECTRIC TUBE

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6 Claims. (Cl. 250—166)

This invention relates to photoelectric tubes and more particularly to the electrode structure and method of sensitizing the cathodes of such tubes.

An object of the invention is to provide an improved form of double anode photoelectric tube.

Another object is to provide an improved process of sensitizing such a photoelectric tube.

In an example of practice illustrative of this invention, a cathode and two anodes are supported from a stem within an evacuated container. The cathode comprises a plate formed into two hollow quarter circular cylinders joined along one edge and curved away from one another so that no portion of either concave surface faces the other concave surface. The anodes are thin wires positioned respectively in front of said concave surfaces and parallel thereto. A sheet of insulating material, such as mica, bisects the space between the convex surfaces of said cathode. From the separated edges of the quarter cylinders two wings extend toward one another. These wings are secured to cathode support wires. Another sheet of mica extends between the separated edges of the quarter cylinders and contacts with the inner surfaces of the wings.

In a preferred method of sensitizing the concave surfaces an electric discharge in oxygen is produced by impressing a potential between the cathode plate and the anodes, the anodes being connected in parallel. The mica sheets facilitate the oxidation of the concave surfaces of the cathode by causing the discharge to take place substantially entirely between the anodes and the concave surfaces. Since these surfaces are preferably silver surfaces, a uniform layer of silver oxide is formed which when treated with caesium vapor under suitable temperature conditions results in a highly efficient photoemissive surface.

A marked improvement in the manufacture of this type of photoelectric tube is effected by the use of these mica sheets particularly by the use of the sheet which bisects the space between the convex surfaces of the quarter cylinders. Without this sheet of insulating material the discharge tends to concentrate on the enclosed surfaces of the cathode including these convex surfaces with the result that a heavier layer of oxide forms on these surfaces than on the concave surface where it is wanted. By preventing oxidation of the convex surfaces according to this invention the concave surfaces may more easily be oxidized to the required degree to produce a highly sensitive light sensitive surface.

Photoelectric tubes according to this invention are particularly useful in the projection of sound from the so-called push-pull sound records. When used for this purpose the anodes are connected separately to the sound circuit. If it is desired to project sound from ordinary sound records the anodes may be connected together. The light beam can then be projected on the whole cathode surface without loss of efficiency because there is no separation between the two concave surfaces of the cathode.

This invention will now be described more in detail having reference to the accompanying drawing.

Fig. 1 shows the structure of a completed photoelectric tube according to this invention.

Fig. 2 is a cross-section of the tube of Fig. 1 perpendicular to the axes of and through the electrodes looking away from the stem.

Fig. 3 is an exploded view of the cathode and insulating plates.

Fig. 4 illustrates a pumping station suitable for processing four tubes concurrently.

Fig. 5 is a schematic electric circuit used in processing such tubes.

The tube illustrated in Fig. 1 comprises a glass bulb 5 having a reentrant stem 6 sealed therein. The stem 6 is provided with a press 7 in which are sealed support wires 8, 9, 10, 11 and 12. To the upper ends of wires 9 and 10 a mica disc 35 is secured, the wires passing through eyelets in the disc and being welded thereto. A bent support wire 13 is welded intermediate its ends to wire 8. The upper end of wire 13 also passes through an eyelet in disc 35 to which it is welded. Wire 13 acts as a third support for disc 35. Cathode 14 comprises a sheet of silver formed into two quarter circular hollow cylinders 15 and 16 joined along one edge 17 and having support wings 18 and 19, as shown in Figs. 2 and 3. The quarter cylinders 15 and 16 and wings 18 and 19 may be formed from a continuous sheet of substantially uniform thickness. The free edges of wings 18 and 19 are bent partially around support wires 9 and 10, respectively, and welded thereto. Anode wires 20 and 21 are welded at one end to support wires 11 and 12, respectively, and held in place at their other ends by passing through eyelets in mica disc 35. These anode wires 20 and 21 are positioned in the front of and parallel to the line elements of the concave surfaces 15 and 16 respectively of cathode 14, approximately in the plane passing through the edges of each surface and approximately equidistant from each edge. These wires 20 and 21 are of molybdenum approximately 10 mils in diameter. The space between the convex surfaces of cylinders 15 and 16 is bisected by a mica sheet 22. Another mica sheet 23 lies against the inner faces of wings 18 and 19 of cathode 14. These two sheets 22 and 23 are substantially at right angles to one another and interconnected at slots 24 and 25. The sheet 22 bears against one side of support rod 13. A nickel baffle 26 is supported from the other end of bent wire 13 to which the baffle 26 is welded. A metallic cup 27 is supported from baffle 26 by means of wire 28. A mixture for producing caesium vapor when heated is carried within the cup 27, the mixture being held in place by metallic gauze 29. The stem is provided with an exhaust tube 30.

A coil 31 is arranged to induce high frequency current in the metal cup 27 for heating the mixture within the cup to its reaction temperature. This coil 31 is used only during the processing of the tube.

Sealed in the press 7 are lead-in wires 32, 33 and 34 connected respectively to support wires 9, 11 and 12. Consequently, lead-in wire 32 is conductively connected to cathode 14. Lead-in wires 33 and 34 are conductively connected respectively to anodes 20 and 21.

A portion of the glass bulb 5 is shown broken away in Fig. 1 for clearness of illustration.

The cross-sectional shape of the cathode 14 and location of the anode wires 20 and 21 are more clearly shown in Fig. 2 which is a cross-section through the tube at the largest diameter of the bulb 5 perpendicular to the axes of the quarter cylinders 15 and 16 looking toward the mica disc 35. Due to the configuration of the cathode 14 and the location of the anodes 20 and 21, substantially all of the electrons emitted from either portions 15 or 16 of the cathode 14 will be collected by the corresponding anode. In view of this fact, the efficiency of the tube when used in the so-called push-pull projection circuit is very high.

The space within the cathode 14 bounded by the convex faces of quarter cylinders 15 and 16 and the support wings 18 and 19 is divided by mica insulators 22 and 23 so that metal does not face metal. Due to such division of this space by insulators there is no tendency for the discharge between the cathode 14 and the anodes 20 and 21 to concentrate on the inside surfaces of the cathode 14 as would be the case were the mica sheets omitted.

The shape of the formed cathode 14 and the mica sheets 22 and 23 are clearly shown in the exploded view of Fig. 3. When assembled sheet 23 lies against the inner faces of support wings 18 and 19, the unslotted portion of sheet 23 lies within the slot 24 of sheet 22 and the unslotted portion of sheet 22 lies within the slot 25 of sheet 23.

The electrodes and accessory structure carried by the stem 6 are fabricated before the stem is sealed into the glass bulb 5. Cathode 14 is formed from a polished silver sheet of a high degree of purity which has a clean mirror finish. The formed cathode is washed and reduced in hydrogen. The concave surfaces of quarter cylinders 15 and 16 of the cathode 14 have a diameter of approximately 1 inch and the length of the cathode is approximately 1⅜ inches.

The caesium producing mixture within the cup 27 is in the form of a compressed pellet which is composed of approximately 3.5 milligrams of caesium chromate $Cs_2CrO_4$, 22.5 milligrams of chromic oxide $Cr_2O_3$, and 9 milligrams of powdered aluminum Al. These ingredients are carefully prepared, finely pulverized and thoroughly mixed in the proper proportions before being formed into pellets.

The pumping station illustrated in Fig. 4 is adapted for the processing of four tubes concurrently. The tubes 5 are sealed to a glass header 40 by means of exhaust tubes 30. This header 40 runs through an oven 41 which comprises a base 42 carrying end supports 43 on the upper ends of which is a metallic cap 44. An electric heater 45 between the supports 43 is surmounted by a removable cover 46 carrying four chimneys 47. This cover is provided with handles 48. The heater 45, cover 46 and chimneys 47 may be raised as a unit so that the chimneys surround the bulbs 5. Each chimney is provided with a slidable baffle (not shown) to control the convection air currents flowing therethrough. With the cover 46 and chimneys 47 removed, the heater 45 may be raised against the cap 44 to completely surround the bulbs 5.

The header 40 is connected to a pumping apparatus comprising a liquid air trap 49, two McLeod gauges 50 and 51, mercury vapor pump 52 and mercury cut-off 53, and a vacuum pump (not shown) connected to tube 54.

Between the mercury cut-off 53 and the liquid air trap 49, two gas supply units 55 and 56 are connected to the pumping apparatus. These units comprise flexible coiled glass tubes 57 associated with gas containers 58 and 59 through mercury seals surrounding pairs of porous plugs of "Lavite," which plugs when brought together permit gas to pass from the respective containers 58 and 59 to the bulbs 5 through the glass coils 57. An ionization manometer 60 is connected to the other end of the header 40.

An electrical circuit used during the processing of four tubes while they are sealed on a pumping station is illustrated in Fig. 5. This circuit comprises conductors 70 adapted to be connected to a direct current source (not shown) and a potentiometer 71 for determining the potentials to be applied between cathodes 14 and anodes 20 and 21 of tubes 5, said anodes being connected in parallel. With switch 72 in its lower position and jack 75 closed, a potential may be impressed on any one of tubes 5 by closing the lower contacts of switch 73 which is individual to such tube. With switch 72 in its upper position, the potential determined by potentiometer 71 is impressed through the upper contacts of all of switches 73 in series on condenser 74 which have a total capacitance of 5 microfarads. Condenser 74 can then be discharged through any of tubes 5 by closing the lower contacts of the corresponding switch 73. The voltage determined by potentiometer 71 is indicated by voltmeter 76. The current flowing through tubes 5 during a later stage of the processing is indicated by ammeter 78 which may be connected into the circuit by inserting plug 77 into jack 75.

The processing of four tubes after the untreated assemblies have been sealed onto the header 40 will now be described.

The tubes 5 are sealed on to the header 40 with the concave sides of the cathode plates 14 facing directly forward, with the bulbs 5 centered with respect to the high frequency coils 31 and at such a height that the cup 27 is approximately midway of the coil 31 longitudinally.

The vacuum pump is turned on. Liquid air trap 49 is cooled with liquid air. When the pressure has fallen sufficiently the manometer 60 is turned on. The heater 45 without the cover 46 and chimneys 47 is raised to engage the cap 44. Current is turned on to bring the oven temperature up to 400° centigrade and maintained until the manometer shows a pressure of $5\times10^{-5}$ millimeters of mercury, or lower, when the current is shut off and the oven allowed to cool. Slow leaks anywhere in the system are indicated if the pressure is not less than $2\times10^{-5}$ millimeters of mercury when the tubes are cooled to room temperature. If leaks are indicated they should be eliminated before the processing proceeds. This treatment removes occluded gases from the bulbs but does not cause any chemical reaction in the caesium pellet. The pumping station is then flushed with oxygen from gas supply unit 58 until a clear green haze is obtained in the manometer 60 which indicates sufficient purity of the oxygen.

Mercury cut-off 53 is now closed to cut off the vacuum pumps and the manometer 60 turned off. Additional oxygen is admitted to a pressure of 2.2 millimeters of mercury as indicated by McLeod gauge 50. Switch 72 of the electrical circuit of Fig. 5 is set in its lower position and the potentiometer 71 adjusted so that the voltmeter 76 shows a voltage of 700 volts. Switches 73 are then operated in succession to close their lower contacts so that each cathode 14 in succession is subjected to positive ion bombardment. Due to the insulation between the convex surfaces of the cathode 14 the bombardment takes place substantially entirely on the concave surfaces of cathode 14. The first effect of such bombardment is to produce a heavy layer of silver oxide on the concave surfaces of cathode 14, followed by a heating-up of the silver plate and reduction of the layer of silver oxide. The cathodes are allowed to cool, the oxygen pressure again adjusted to 2.2 millimeters of mercury and the oxidation, reduction and cooling repeated. The mercury cut-off 53 is then opened and the oxygen pumped out. This treatment leaves the concave surfaces 15 and 16 of each cathode 14 clean and slightly rough so that it has a uniform matte finish.

After a good vacuum has again been obtained as indicated by manometer 60, the mercury cut-off 53 is again closed and the manometer turned off. A fresh charge of oxygen through gas supply unit 55 is admitted to a pressure of 0.75 millimeter of mercury. Switch 72 is thrown to its upper position after potentiometer 71 has been adjusted so that the voltmeter 76 shows a voltage of 650 volts. Each tube 5 is then subjected to a series of discharges from condenser 74 by the operation of closing switches 73 on their lower contacts. This operation is hereinafter called "tapping." Switch 72 in its upper position is therefore said to be in the "tapping" position. Each switch 73 is tapped sixty times in three groups of twenty taps each. The first group of taps is applied to the four tubes in succession, then the second group and so on until each tube has received the required number of taps or discharges. The mercury cut-off 53 is again opened and the pumping continued until the pressure is down to $3\times10^{-5}$ millimeters of mercury or less.

This treatment with oxygen by tapping produces a thin layer of silver oxide on the concave surfaces of each cathode 14. At each tapping of a switch 73 a glow discharge occurs in the associated tube 5 and the cathode 14 of that tube is bombarded with a definite number of positive ions. The amount of silver oxide which is formed is therefore closely controlled because the discharge is confined to the concave surfaces 15 and 16.

The cathodes 14 are now in condition to be treated with caesium vapor under suitable temperature conditions. A source of high frequency current (not shown) is connected to coils 31 in succession to "flash" the caesium pellets, that is, to induce sufficient current in the cups 27 to start a chemical reaction of the ingredients of the caesium pellet. The exothermic reaction which follows develops a large amount of heat and causes the immediate and complete expulsion of all of the caesium. The high frequency source is disconnected as soon as the reaction starts. The caesium, as it travels from the open end of cup 27 through metal gauze 29, is deflected by baffle 26 and is condensed on the glass walls of the bulb 5 in front of the oxidized surface of the cathode 14. The baffle 26 prevents the hot caesium vapor from impinging directly on the cathode surface. This baffle 26 is so shaped that it lies substantially parallel to the magnetic lines of force produced by the high frequency current in coil 31 and therefore is not heated to any great extent by eddy currents induced therein.

Immediately after the caesium pellet has been flashed stem heaters (not shown) are inserted around the stems of the tubes 5. Thermocouples are placed against each bulb 5 at the surface opposite the stem to indicate temperatures. The cover 46 with the chimneys 47 are placed on the heater 45 and the whole raised until a chimney 47 surrounds each bulb 5. The stem heaters are turned on first and after two minutes the heater 45 is turned on to quickly bring up the temperature of the convection air currents flowing past the bulbs 5. When the hottest bulb reaches a temperature of 150° centigrade the heater 45 is regulated to hold this temperature for five minutes. At the end of this five-minute period the heater 45 is again regulated to raise the temperature of the air currents to quickly bring the temperature of the hottest bulb 5 up to 225° centigrade. The heater 45 is then regulated to hold this temperature until the cathode surface of each tube has reached the proper sensitivity.

The sensitivity may be indicated by the ammeter 78 when connected into the circuit of Fig. 5 by the insertion of plug 77 into jack 75. Each cathode 14 may be illuminated by a source of light (not shown). The potentiometer 71 is adjusted to give a voltage of 50 volts, as shown on voltmeter 76. Switch 72 is closed in its lower position. The sensitivity of each tube 5 will be indicated by the ammeter 78 if the corresponding switch 73 is closed in its lower position. The tubes 5 are tested from time to time while illuminated and the hot air treatment is continued until the photoelectric current tends to decrease. As each tube reaches its proper sensitivity the air current for that tube is cut off. When all of the tubes have reached the proper sensitivity the chimneys 47 are lowered and the bulbs allowed to cool to room temperature with the pumping apparatus still on.

When the bulbs 5 have cooled and the pressure is down to $2\times10^{-5}$ millimeters of mercury, mercury cut-off 53 is closed and argon is admitted from the gas supply unit 59. The argon is admitted until the pressure assumes a steady state at the desired value, when the tube is sealed off from the header 40 by sealing the exhaust tube 30. The pressure of argon is dependent upon the amount of gas amplification desired in the completed tube. A suitable pressure is $5\times10^{-2}$ millimeters of mercury.

The cathode 14 may comprise a nickel or copper sheet having a surface layer of silver which is processed in the manner hereinbefore described to render it photosensitive. The preliminary roughening of the silver surface may be accomplished in other ways than by oxidation and reduction of the silver oxide, as, for example, by sandblasting, etching with acid, or even by applying a coating of silver oxide and a binder with a brush or air spray and reducing the silver oxide to metallic silver by heat.

The cathodes may also be sensitized by subjecting the oxidized silver surface to the vapor of the other alkali metals, rubidium, lithium, potassium and sodium. The temperature conditions would be varied somewhat depending upon the materials being used.

What is claimed is:

1. A photoelectric tube comprising an evacuated container, a metallic cathode plate comprising two concave quarter-cylindrical surfaces of quarter circular cross-section joined along one edge and curved away from each other so that a straight line joining any point within the quadrant of one surface with any point within the quadrant of the other surface intersects both surfaces, metallic means extending from the outer edges of said cylinders toward each other, means supporting said cathode within said container, two anodes also supported within said container in front of said cathode surfaces respectively and parallel thereto lying in a plane intersecting both cathode surfaces intermediate said anodes, a sheet of insulating material extending from the joined edges of said cathode to a point between said metallic means which extends from the outer edges, and a light sensitive electric layer on both said concave surfaces.

2. A photoelectric tube comprising a cathode composed of sheet metal of approximately uniform thickness formed with portions of one side of the sheet turned toward each other and portions of the other side of the sheet turned away from each other, insulation in the space between the portions turned toward each other, an anode in the space in front of the portions turned away from each other, and means mounting said cathode, anode and insulation in said specified relationship in an evacuated container.

3. A photoelectric tube comprising an evacuated container, a cathode element in the form of a hollow open-ended member whose outer surface is a nearly closed cylinder having a cross-section resembling an arrowhead, a pair of anodes outside said cathode element, and a sheet of insulation bisecting longitudinally the space within said cathode element.

4. A photoelectric tube comprising an evacuated container, a metallic cathode plate comprising two concave quarter-cylindrical surfaces of quarter circular cross-section joined along one edge and curved away from each other so that a straight line joining any point within the quadrant of one surface with any point within the quadrant of the other surface intersects both surfaces, means supporting said cathode plate within said container, two anodes also supported within said container in front of said concave surfaces respectively and parallel thereto lying in a plane intersecting both cathode surfaces intermediate said anodes, a sheet of insulating material between the cylindrical surfaces of said cathode extending from the joined edges of said cathode to a plane passing through the remote edges of said cathode, and a light sensitive electric layer on both said concave surfaces.

5. A photoelectric tube comprising a light pervious envelope with a reentrant stem supporting side by side two parallel sheet-like photoelectric cathodes sensitized with light responsive material on one surface and with adjacent edges joined together and with the perpendicular planes bisecting the light sensitive surfaces intersecting each other on a line behind the light sensitive surfaces, electron collecting means in front of said light sensitive surfaces, and a sheet of insulating material extending from said joined edges to a plane passing through the outer edges of said cathodes.

6. A photoelectric tube comprising a container having therein a cathode the rear surface of which comprises portions generally convergent toward a central portion, an anode structure near the front surface of said cathode, a gas filling of such density that a glow discharge takes place between said cathode and anode when a suitable potential is applied therebetween, said glow discharge taking place partly between said anode and the rear surface of said cathode when there is a clear space between said convergent portions, and means in said space offering impedance to the ionic flow to or from said surface to cause the discharge to be predominantly or wholly within the region between the front surface of said cathode and said anode structure.

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