June 28, 1960 B. G. FIRTH ET AL 2,943,225

COLD CATHODE VACUUM TUBE DEVICES

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Fig. 1.

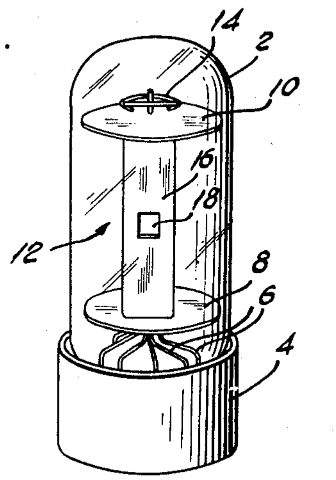

Fig. 2.

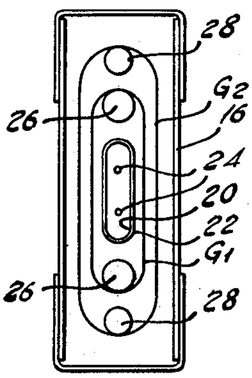

Fig. 4.

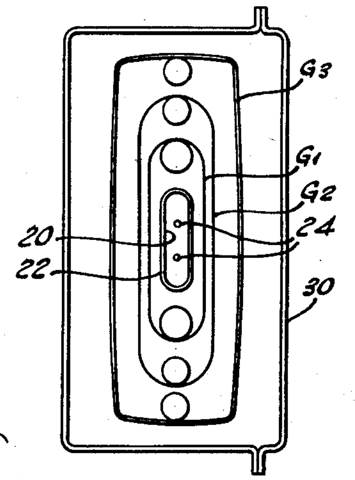

Fig. 3.

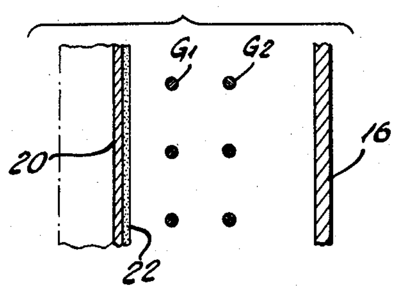

Fig. 5.

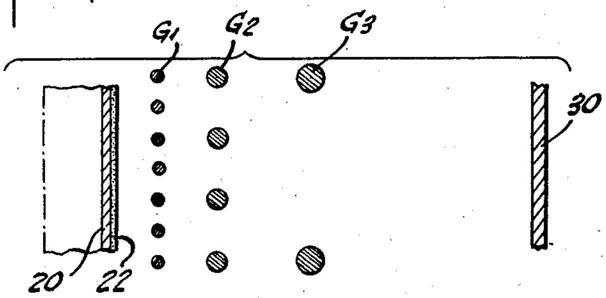

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FIG. 6a.

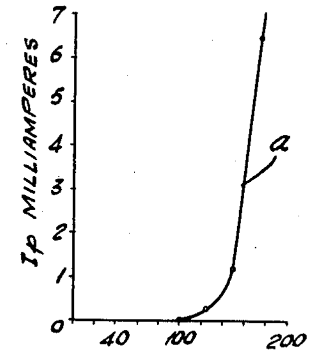


FIG. 6b.

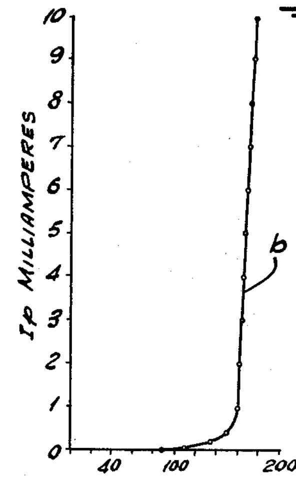


FIG. 7.

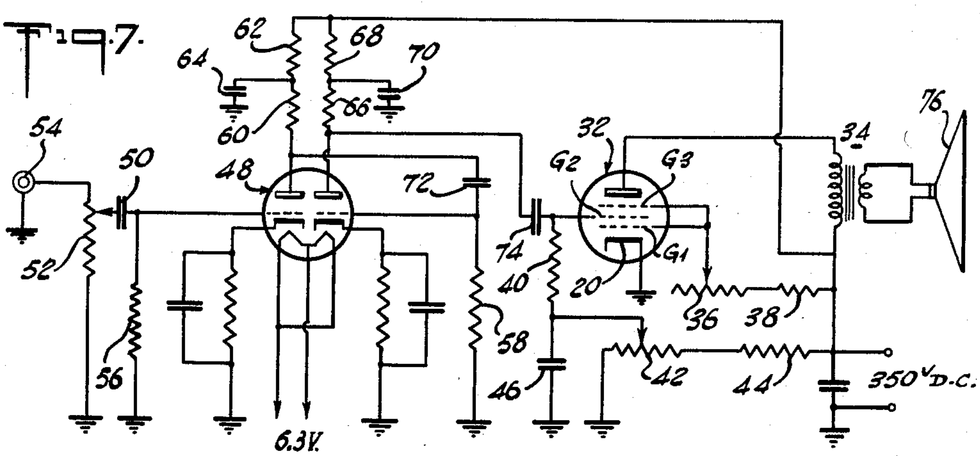
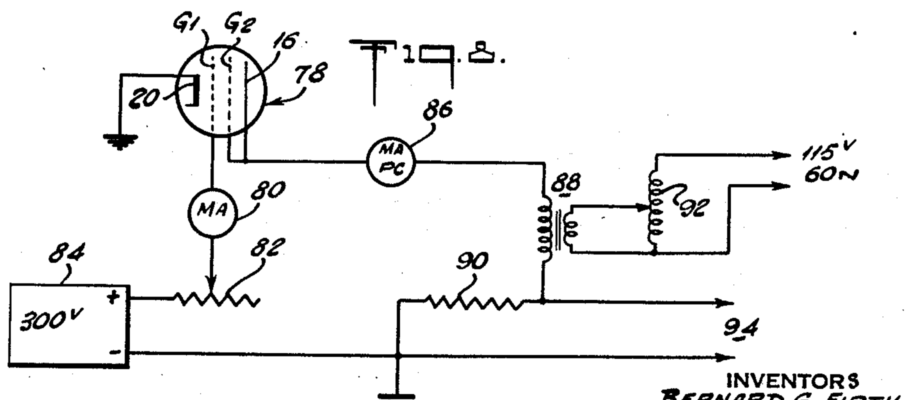


FIG. 8.



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COLD CATHODE VACUUM TUBE DEVICES

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5 Claims. (Cl. 313—293)

The present invention relates to amplifying and rectifying devices and comprises a novel multi-electrode vacuum tube employing a cold cathode. Two electrode cold cathode vacuum tubes have heretofore been known but their utility has been relatively limited to use as noise generators or the like. One such device is disclosed in Dobischek et al. Patent No. 2,802,127. Cold cathodes have many advantages over the usual heated cathodes of vacuum tubes. The delay at starting incident to heating up the cathode is eliminated. Less power is required for electron emission, that for a cold cathode being of the order of a few milliwatts whereas in hot cathode vacuum tubes the power consumed by the cathode heater is of the order of 4 to 6 watts. As it is the failure of the filament heater which primarily determines the life of the usual hot cathode tube, substantially longer life can be expected for tubes having cold cathodes. A further advantage inherent in the use of a cold cathode is that the requirement for a battery or other source of potential for the cathode heater is eliminated.

Cold cathodes for vacuum tubes have an oxide coating thereon, preferably magnesium oxide in relatively porous form. The oxide coating comprises a uniform distribution of microscopic sponge-like structures. Once initiated, emission of electrons from such type of coating is copious and self-sustaining provided a collector electrode of higher potential is present to attract the emitted electrons. When emitting electrons the oxide coating glows with a blue or violet luminescence. Initiation of emission may be effected by subjecting the coating to radiation from a source of ultraviolet light, by bombarding the coating with primary electrons thermally generated within the envelope, by bombardment with high velocity electrons emitted by field emission from a pointed electrode within the evacuated envelope and by excitation with a high frequency Tesla coil. Once electron emission is initiated an electrode, maintained at a positive potential with respect to the surface of the oxide coating, sustains the emission.

Ordinary electron tube techniques have not been readily applicable to this type of tube. For example, in the ordinary three electrode hot cathode vacuum tube amplifier, amplification is effected by control of the grid potential and effective amplification requires that the control grid draw a minimum amount of current. For this reason in triode amplifiers using hot cathodes the potential of the control grid is ordinarily maintained at or below the potential of the cathode. In a cold cathode tube device, however, if a control grid is positioned between the emitting cold cathode and the collector electrode, electron emission can not be sustained unless the potential of the control grid is substantially higher than that of the cathode.

We have been able to produce cold cathode vacuum tube amplifiers of moderate transconductance, with good control of plate current and of stable operation. These new amplifiers have at least four electrodes, the four electrodes being the cold cathode, a keep-alive or collector grid maintained at a potential positive with respect to that of the cathode, a control grid surrounding the collector grid and a plate or anode surrounding the control grid. To assure stable operation with such cold cathode vacuum tetrode it is important that the emitting surface of the cathode be shielded from the glass walls of the envelope. The tetrode construction of the invention is also suitable for use as a half-wave rectifier. We have also produced a cold cathode vacuum tube amplifier of relatively high transconductance and of stable operation in a pentode construction, the fifth electrode comprising a grid positioned between the plate and control grid.

The first cold cathode vacuum tube diodes employed cylindrical or semi-cylindrical cathodes and collector grids. We have found that such type of construction does not lend itself to production of efficient amplifiers. Our presently preferred amplifier construction is the result of substantial experimentation with respect to shape of cathode, grids and anode, with respect to inter-electrode spacing and with respect to the location and number of grid wires. Because the vacuum tube amplifiers of the invention are believed to be the first to utilize cold cathodes, dimensional values for the various parts of the amplifiers illustrated in the accompanying drawings will be given. The invention is not limited to the specific details which follow.

Of the accompanying drawings:

Fig. 1 is a perspective view of a cold cathode vacuum tube amplifier embodying the invention;

Fig. 2 is a diagrammatic horizontal sectional view through a four electrode structure of an amplifier such as that of Fig. 1;

Fig. 3 is a partial half longitudinal sectional view, on an enlarged scale, of the electrode structure of Fig. 2;

Fig. 4 is a diagrammatic horizontal sectional view similar to that of Fig. 2 but representing a pentode;

Fig. 5 is a partial half longitudinal sectional view of the five electrode structure of Fig. 4;

Figs. 6a and 6b are graphs showing characteristic curves of the tetrode and pentode of Figs. 3 and 5 respectively;

Fig. 7 is a circuit diagram illustrative of the use of the pentode amplifier of the invention; and

Fig. 8 is a diagram illustrating use of the tetrode structure of Figs. 2 and 3 as a half-wave rectifier.

The tube illustrated in Fig. 1, which may be either a tetrode or a pentode, comprises an evacuated envelope **2** of glass or the like, a base **4** of Bakelite or other insulating material within which is the stem or press, not visible in the view of Fig. 1, through which the various support leads are fused. Also within the envelope **2** and mounted between two mica discs **8** and **10**, is the electrode structure designated generally by the reference numeral **12**. Above the top mica disc **10** is a conventional getter assembly **14**. The anode **16** of the electrode assembly **12** is generally rectangular in horizontal section. In each of the narrow side walls of the anode a window **18** is provided to insure complete exhaust of the electrode structure during evacuation of the tube.

For a tetrode construction, a horizontal sectional view of the electrode assembly **12** of Fig. 1 will appear as shown in Fig. 2. A cathode sleeve **20** of nickel is spray coated with a layer **22** of magnesium oxide. The layer is .0015″ thick and terminates short of each end of the sleeve to leave about 5 millimeters at each end uncoated. The oxide coating is terminated short of the ends of the sleeve to avoid possible influence on tube characteristics of electrostatic charges accumulated by the mica wafers **8** and **10**. The coating, as previously indicated, should be porous and sponge-like to insure copious and self-sustaining electrode emission, once the emission is initiated. Prior to evacuation of the envelope the cathode is processed in air at about 800° C. and 100 millimeters pressure. For this purpose an insulation coated heavy tungsten wire heater **24** is provided within the nickel sleeve **20**, the heater being a standard 6.3 volt 1.2 amp. heater of the type employed in some hot cathode electron tubes. The heater **24** is used only for such processing. Surrounding the coated cathode is a grid G_1 mounted on support posts **26** and surrounding the grid G_1 is a second grid G_2 mounted on grid posts **28**. As shown best in Fig. 3, the turns of grid G_1 and of grid G_2 are in horizontal alignment. In the particular tetrode illustrated each grid has 42 turns of wire per inch and the spacing between grid G_1 and the outer surface of the coating **22** is .015" whereas that between the planes of the twe grids is .0215", the diameters of each grid wire being .004". The rectangular anode **16** encloses the cathode and grids, being spaced in the view of Fig. 3 from the plane of grid G_2, a distance of .030".

With the above described construction, with grid G_1 at a voltage of 200 v. above cathode potential and plate voltage of 350 v. the plate current varies with the voltage of grid G_2 as shown by the curve *a* of Fig. 6*a*. In the particular circuit used for obtaining data represented by curve *a*, a resistor of 25 kilohms was connected in the circuit of grid G_1 and the current taken by such grid was between 2.9 and 3.2 milliamps.

The fact that in the operation of the above described tetrode the first grid is maintained positive with respect to the cathode might lead to the assumption that the tube operation was similar to space charge grid operation of the conventional hot cathode vacuum tube. Actually there is only a superficial resemblance. In the new tube there is no space charge close to the cathode. Because of the avalanche effect of the electron stream from the magnesium oxide cathode coating, the outer surface of the coating is about 70 volts positive with respect to the sleeve and electrons leave the surface, it is believed, with about zero velocity. Thus, unless a grid is at a potential of more than 70 volts above the cathode sleeve, it will not collect electrons. The action of the control grid in the new tetrode is somewhat similar to the action of a suppressor grid in a hot cathode pentode when it is being used as a control for the electron stream.

In the pentode construction illustrated in Figs. 4 and 5 and an additional grid, G_3 is provided and positioned between grid G_2 and the anode **30**. Grid G_3 serves much the same purpose as does a screen grid in conventional tetrodes. When tied to grid G_1, it shields the cathode from voltage variations at the plate and increases gain. In the particular pentode construction shown in Figs. 4 and 5 grid G_1 is of .002" diameter wire and of 150 turns per inch. Grid G_2 is of .003" diameter wire and of 75 turns per inch. Grid G_3 is of 23 turns per inch and has a greater diameter, namely .005", than that of either grid G_1 or G_2. Grid G_1 is spaced .0135" from the cathode. Grid G_2 is spaced .0220" from the plane of grid G_1 and grid G_3 is spaced .0340" from the plane of grid G_2. The spacing between plate **30** and the plane of grid G_3 is .0765". With grids G_1 and G_3 tied together and maintained at 200 v. above cathode potential and with a plate voltage of 350 v. the curve *b* of Fig. 6*b* was obtained. The current to grids G_1 and G_3 varied from 7.6 to 8.4 milliamps.

The curves *a* and *b* for the respective tetrode and pentode of the invention show usable transconductance of the tubes and good amplification. A transconductance of the tubes and good amplification. A transconductance of 212 micromhos for the tetrode is shown by curve *a* and of 600 micromhos for the pentode is shown by curve *b*.

Fig. 7 represents one particular circuit in which the new pentode has been employed for amplification of play back of a recorder. In Fig. 7 the new cold cathode vacuum tube pentode is represented conventionally and indicated by the reference numeral **32**. It is shown connected as an amplifier with its plate connected through the primary of an output transformer **34** to the positive terminal of a source of 350 v. direct current, with its grids G_1 and G_3 tied together and connected through a variable resistor **36** and fixed resistor **38** to the positive terminal of the source. The cathode of tube **32** is grounded and its control grid G_2 is connected through a resistor **40** to a tap on a potential divider **42**, the potential divider being conected in series with a resistor **44** across the source. A capacitor **46** is connected between the tap on divider **42** and ground. A preamplifier **48**, which may be a 12AU7, has the control grid of its first half connected through a capacitor **50** to a tap on a resistor **52** connected between ground and the underground terminal of a jack **54**, the jack serving for connection to a photograph pickup. A bias resistor **56** is provided for the control grid of the first half of amplifier **48** and a similar bias resistor **58** is provided for the control grid of the second half of the amplifier **48**. The anode of the first half of amplifier **48** is connected through two series connected potential dropping resistors **60** and **62** to the positive terminal of the source, the junction of the resistors being conected to ground through a by-pass capacitor **64**. Similarly, the anode of the second half of amplifier **48** is connected through twe series connected potential dropping resistors **66** and **68** to the positive terminal of the source, the junction of resistors **66** and **68** being connected to ground through a by-pass capacitor **70**. The anode of the first half of the amplifier is coupled through a capacitor **72** to the control grid of the second half of the tube and the anode of the second half of the tube is connected through a capacitor **74** to the control grid G_2 of the pentode **32**. Each of the cathodes of the amplifier **48** is connected to ground through and RC circuit and the heaters for the amplifier are connected in parallel to an A.C. source of 6.3 volts. A loudspeaker **76** is coupled to the secondary of transformer **34**. With the above described circuit, large output volume was obtained with good reproduction thus demonstrating the utility of the new cold cathode pentode construction.

When the outer grid G_2 and the anode of a tetrode construction similar to that of Figs. 2 and 3 except that grid G_2 preferably has fewer turns per inch, are tied together, the tube may be used as a half-wave rectifier. The diagram of Fig. 8 illustrates such use, the tube being represented conventionally therein at **78**. In the particular circuit of Fig. 8, the cathode **20** of the tube is grounded. Grid G_1 is connected through a milliammeter **80** and variable resistor **82** to the positive terminal of a source **84** of say 300 volts, the negative terminal of which is grounded. The anode **16** and grid G_2 are tied together and connected through a milliammeter **86**, the secondary of a transformer **88** and a resistor **90** to ground. Alternating current to be rectified is impressed across the primary of transformer **88** from a variac **92** across which 115 volt 60 cycle supply voltage is impressed. Output terminals **94** for the rectified current are connected to opposite ends of resistor **90**. Suitable values for resistors **82** and **90** are fifty kilohms and one kilohm, respectively. An oscillograph connected across terminals **94** of the above described circuit showed effective rectification without distortion of perceptible flicker or flashback.

Specific amplifiers embodying the invention have now been described. Obviously variations from the particular designs or dimensions given herein can be made without departing from the spirit of the invention or the scope of the appended claims.

It will be understood, that before the new device can function as an amplifier or rectifier electron emission from the cathode coating must be initiated. Some known methods and devices for initiating emission have been briefly described.

In an application of Albert M. Skellett, Serial No. 745,149, filed June 27, 1958, there is described a starting device comprising an electroluminescent source of ultraviolet light positioned within the evacuated envelope so as to flood the coated cathode with ultraviolet light when energized from an external source of energy. Such a starting device could be incorporated in the devices of the present invention. In an application of Bernard G. Firth, Serial No. 745,162, also filed June 27, 1958, there is described an external "keep alive" circuit arrangement which permits rapid restarting of a cold cathode vacuum tube after relatively long periods during which the cathode current is so minute that luminescence of the oxide coating ceases. Such "keep alive" circuits could be advantageously employed with the devices of the present invention, separate starting means being employed only for initial starting.

The following is claimed:

1. A vacuum tube amplifier comprising a cold cathode having an oxide coating thereon comprising a uniform distribution of microscopic sponge-like structures capable of self-sustained electron emission once electron emission has been initiated, a first grid of equally spaced grid wires surrounding said cathode for sustaining electron emission from the cathode while permitting passage of electrons therethrough, a second grid of equally spaced grid wires surrounding said first grid with its wires aligned with those of said first grid and an anode surrounding said second grid, said second grid serving as a control grid to control electron flow to said anode.

2. The vacuum tube amplifier according to claim 1 wherein the spacing between said second grid and anode is greater than that between said grids and than that between said first grid and cathode.

3. The vacuum tube amplifier according to claim 1 wherein a third grid of equally spaced wires surrounds said second grid and is surrounded by said anode, there being fewer grid wire turns of said third grid than of either said first or second grid, said third grid, when electrically tied to said first grid serving to shield the cathode from voltage variations at the anode.

4. A pentode amplifier comprising an evacuated envelope having mounted therein a cold cathode comprising a metallic sleeve having a porous spongy oxide coating thereon, said cathode being capable of self-sustained electron emission once electron emission has been initiated, a keep-alive electrode for sustaining electron emission from the cathode while permitting passage of electrons therethrough, a control grid, a screen grid electrically tied to said keep-alive electrode and an anode.

5. A half-wave rectifier comprising an evacuated envelope having mounted therein a cold cathode comprising a metallic sleeve having a porous magnesium oxide coating thereon, said cathode being capable of self-sustained electron emission once electron emission has been initiated, a keep-alive electrode for sustaining electron emission from the cathode while permitting passage of electrons therethrough, a grid and an anode, said grid and anode being electrically tied together.

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