Nov. 4, 1952 J. H. COLEMAN 2,616,986

COLD CATHODE GAS-FILLED AMPLIFIER TUBE

Filed Oct. 30, 1948

Fig.1

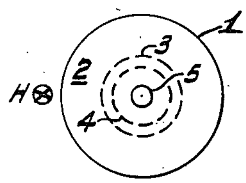


Fig.2

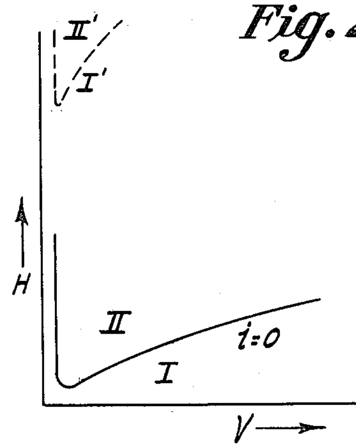


Fig.3

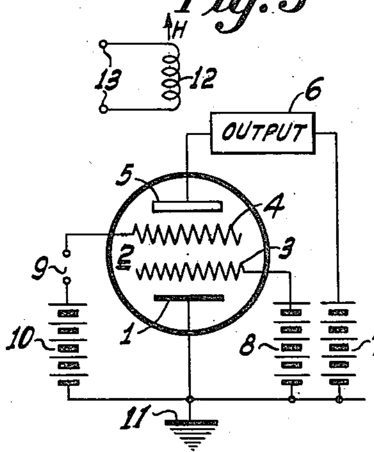


Fig.4

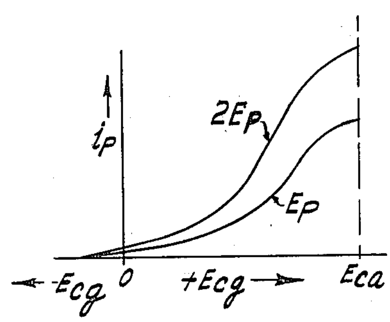
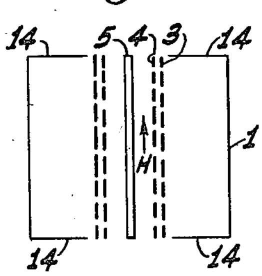


Fig.5



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COLD CATHODE GAS-FILLED AMPLIFIER TUBE

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4 Claims. (Cl. 179—171)

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This invention relates to cold cathode gas filled amplifier tubes and to circuits associated therewith, and more particularly to such tubes upon the gaseous mediums of which are impressed a magnetic field at right angles to the electric fields required in the operation of such tubes.

In the conventional cold cathode gas filled amplifier tubes as heretofore known, the gaseous medium in the tube was divided into two regions (1) an outer region between the cathode and the cathanode and (2) an inner region between the cathanode and the plate. A control grid was positioned in the inner region.

In operation, an auxiliary or initial discharge was produced between the cathode and the cathanode by the residual ion pairs of free electrons in the outer region being accelerated by an impressed electric field to ionizing velocities. The electrons of the resulting conduction currents were accelerated toward and passed through the cathanode and were then accelerated through the inner region to the plate by a second electric field. In this inner region, the control grid, connected to the source of grid currents to be amplified, modulated the flow of electrons and thus amplified the currents in the control grid circuit of the tube.

These conventional cold cathode amplifier tubes were not successful because of the further ionization taking place in the inner region, which produced excessive noise in the output circuit and excessive grid currents. Attempts were made to reduce this noise by decreasing the plate voltage. These attempts were not successful as the plate voltages had to be reduced to values below practical operating voltages and it was practically impossible to produce uniform tubes (see Electronics, April 1935, p. 131).

These disadvantages have been overcome in the present invention controlling the paths of auxiliary discharge electrons by a magnetic field that is impressed upon the medium at right angles to the required electric fields, the magnetic field being of such value that sufficient ionization is assured in the outer region and little, if any, ionization takes place in the inner region. The present invention permits the use of high voltages on the plate of the tube, without ionization noise.

This invention includes depositing on one of the electrodes defining the outer region a radioactive isotope so that nuclear charged particles traverse the outer region, and making the other electrode of the outer region of a secondary electron emission responsive material to provide an

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abundant supply of electrons for the auxiliary or initial conduction currents generated in the outer region.

The radioactive isotope is not required for the practicing of the invention, but the operation of the device is improved by such use.

Among the objects of the invention are to provide improved methods of and means for amplifying electric currents.

Another object is to reduce the noise heretofore experienced in cold cathode gas filled amplifier tubes.

Another object is to permit the use of higher anode voltages on cold cathode gas filled amplifier tubes than has heretofore been practical.

Another object is to amplify electric currents by a cold cathode gas filled tube, upon the medium of which tube is impressed on a magnetic field and electric fields, the magnetic field being at right angles to the electric fields.

Another object of the invention is to initiate by ionization large conduction currents in the outer region of a cold cathode gas filled amplifier tube by bombarding a secondary electron responsive electrode in that region by a radiation of nuclear charged particles and extending the paths of the secondary electrons beyond the mean free path for ionization by collision and at the same time reduce or prevent ionization in the inner region.

Other objects will be apparent from the description of the invention as hereinafter set forth in detail and from the drawings made a part hereof in which Figure 1 is a schematic sketch of the tube at a horizontal cross section; Figure 2 is a graph showing the relation of the values of the magnetic field impressed upon the two regions of the medium of the tube to the values of the potentials between the electrodes of the tube to satisfy the condition that the medium between the respective electrodes are just non-conducting; Figure 3 is a conventional schematic drawing of cold electrode gas filled amplifier tube and associated circuits; Figure 4 is a graph showing the relation of the values of plate current to control grid voltages for two values of plate voltages; and Figure 5 is a schematic vertical cross section sketch of a modification of the tube shown in Figure 1.

Similar reference characters are applied to similar elements throughout the drawings.

Referring to Figure 1, 1 represents the envelope of a tube, shown generally at 2. Tube 2 is cylindrical in shape as well as the elements therein, and is evacuated to a pressure of 10^{-3} to 10^{-5} mm. Hg.

Envelope 1 is also the cold cathode of the tube, at a distance Rc from the axis of the tube. Envelope 1 is made of some magnetic field permeable substance capable of maintaining the high vacuum of the tube and also secondary electron emission responsive. Aluminum has been found to be a suitable material.

Inside of and parallel to cathode 1 is cathanode grid 3 of the tube, at a distance of Rca from the axis of the tube. Inside grid 3 is control grid 4, at a distance of Rcg from the axis of the tube. Inside grid 4 is the plate 5, which is a hollow tube with a radius of Rp.

A magnetic field H is impressed upon the medium of the tube by any conventional method such as a solenoid (not shown in this figure), the field being indicated in Figure 1 as H⊗, that is, the direction of the field is as if coming out of the plane of the drawing.

Referring to Figure 3, the tube and its elements are shown in the conventional vacuum tube schematic diagram to illustrate in a better form the elements of tube and its exterior circuits. 6 represents the load or output of the tube, which load is connected in series with electric source 7, load 6 and source 7 being connected as a unit between plate 5 and cathode 1.

Electric source 8 is connected between cathanode 3 and cathode 1.

Grid 4 is connected to the electric currents from source 9, that are to be amplified, and through source 9 and biasing electric source 10 to cathode 1. Cathode 1 is grounded at 11.

Magnetic field H is produced by solenoid 12 connected to direct-current source 13.

The operation of the device will first be explained in the preferred positioning of the radioactive material on the cathanode. When a radioactive material, such as phosphorus^{32}, which is a pure beta emitter with a range of energies up to 1 m. e. v., is deposited on cathanode 3, beta charged particles are radiated in random directions across the outer region.

Under the influence of magnetic field H, the paths of these electrons are deflected and the electrons bombard cathode 1 at various angles of incidence causing secondary emission of electrons.

The secondary electrons are emitted at velocities lower than the primary electrons from the radioactive source, but they are likewise deflected in their paths. At some critical values of magnetic fields, the potentials of the source (cathanode 3) and the relative radii of the secondary emitting electrode (cathode 1) and source, the electrons are so deflected as to be cut-off from striking, or pass by, the cathanode 3. The electrons are thereby trapped within the outer region and, continuing on their paths, strike the cathode and cause further secondary emission. The paths of these trapped electrons are extended by their reflection from the surface of cathode 1 until their mean free paths exceed the mean free paths of molecules in the medium and cumulative ionization by collision occurs and large conduction currents flow from cathode 1 toward and through cathanode 3, as long as cathanode 3 is positive with respect to cathode 1.

From observations, the magnetic field-voltage relation for the minimum conditions for the outer region of the tube to be conductive, has been plotted as the lower or solid curve in Figure 2. This curve defines the non-conductive region I and the conductive region II.

The lower part of this curve corresponds closely to the theoretical or mathematical analysis of the reactions as set forth in the equation

$$H_0=\frac{Rca}{Rc^2}\sqrt{\frac{8m}{e}}\cdot\sqrt{V} \qquad (1)$$

where H_0 is the strength of the magnetic field in the outer region, Rca is the radius of the cathanode 3, Rc is the radius of the cathode 1, m is the mass of the electron, e is the charge of the electron, V is the potential of the cathanode 3, all in c. g. s. units (see Hull, Physical Review, 1921, volume 18, page 35).

In the inner region, between cathanode 3 and plate 5, the same strength conditions of magnetic field exist, but conduction in this region will not occur except with much higher values of magnetic field. This is apparent when the differences in the radii of the involved elements of the tube are considered.

The lower part of the upper (dotted) curve in Figure 3 may be defined by the equation

$$Hi=\frac{Rp}{Rca^2}\sqrt{\frac{8m}{e}}\sqrt{V} \qquad (2)$$

where Hi is the strength of the magnetic field in the inner region Rp is the radius of the plate, Rca is the radius of the cathanode, m is the mass of the electron, e is the charge of the electron and V is the voltage of the plate, all in c. g. s. units. This curve defines the non-conductive region I′ and the conductive region II′.

Thus, the ratio of the magnetic fields necessary for conduction at the same voltage across the outer and the inner regions is given by

$$\frac{(1)}{(2)}=\frac{H_0}{Hi}=\frac{(Rca)^3}{Rp(Rc)^2} \qquad (3)$$

Since $(Rca)^2<<(Rc)^2$ for practical dimensions, then

$$\frac{H_0}{Hi}\ll 1 \qquad (4)$$

It is thus apparent that for operation of the device in the low magnetic field region, a large amount of ionization occurs at low pressures in the outer region while only a negligible, if any, ionization occurs in the inner region.

The above-mentioned factors thereby provide control of generated electron conduction currents resulting from selective ionization of the gas medium disposed within the amplifying device.

The reactions within the inner region tube is the same as in the conventional cold cathode gas filled amplifier tube. The electrons passing through the cathanode are drawn toward the plate under the influence of the high positive potential on the plate. In the paths of these electrons is positioned the control grid 4, which is connected in the control grid 4 circuit of the tube. The potentials on the grid 4 are therefore characteristic of the currents to be amplified. By positioning of grid 4 in relation to cathanode 3 and by electric biasing grid 4 by electric source 10, as is well known in the art, the intensity of stream of electrons between cathanode 3 and plate 5 is modulated and this modulated stream becomes the amplified currents.

A typical grid transconductance curve is plotted in Figure 4, where E_{cg} is the total voltage on the control grid 4 and i_p is the resulting plate current. Curves for two values of plate voltages, E_p and $2E_p$ are plotted. The plots are extended in abscissa values, of course, only to the value E_{cg} equals E_{ca}.

It has been found that the ionization efficiency of the device is increased considerably by constructing the cathode 1 in a form shown in Figure 5, that is, by adding end plates 14 to the cylindrical form described hereinbefore in connection with Figure 1. The reason for this increase in efficiency is believed to be that the magnetic field ratio (H_0/H_i) is made smaller for the same radii of the involved elements of the tube.

As stated hereinbefore, the radioactive material is preferably mounted on the cathanode. It has been found that when the radioactive material is mounted on any of the electrodes of the tube, so that the emitted particle traverse the outer region and impinge on the surface of the cathode, the stability of the ionization is increased.

The operation of the device when no radioactive isotope is associated with the outer region is the same as previously described except that the source of the ionization initiating electrons is the residual or free electrons present in the medium. These electrons respond to the electric field between the anode and the cathanode and to magnetic field in the same manner as described for the secondary emission electrons.

There is thus disclosed and described an invention comprising a cold cathode gas filled amplifier tube and associated circuits, in which tube may be positioned a radioactive source of radiation adjacent to a secondary electron emission responsive element, and upon the medium of which tubes is impressed a magnetic field. This field and electric fields at right angles to the magnetic field, produce extensive ionization in the outer region of the tube and little, if any, ionization in the inner region of the tube, and by controlling or modulating the stream of electrons traversing the inner region by potentials corresponding to the characteristics of the currents to be amplified, the amplified currents are produced.

I claim as my invention:

1. Apparatus for amplifying signal currents comprising a gas-filled-medium amplifier tube having a secondary emission responsive cold cathode, a cathanode, a control grid, and a plate, an outer region between said cold cathode and said cathanode and an inner region between said cathanode and said plate, a source of primary charged particles adjacent said secondary emission responsive cold cathode for bombarding said cathode with said primary charged particles to produce secondarily emitted electrons, means for trapping said secondarily emitted electrons within said outer region and extending the paths of said electrons beyond the mean free electron path necessary for ionization, means for causing said electrons to flow through said inner region to said plate, means for modulating said electron flow in accordance with the characteristics of said currents to be amplified, and means for collecting said modulated currents.

2. Apparatus as claimed in claim 1 characterized by said plate, control grid, cathanode, and cathode being cylindrical in form with plates attached to each end of and extending axially inward from said cathode.

3. Apparatus for amplifying signal currents comprising a gas-filled-medium amplifier tube having a secondary emission responsive cold cathode, a cathanode, a control grid, and a plate, an outer region between said cold cathode and said cathanode and an inner region between said plate, a source of primary radioactive charged particles adjacent said secondary emission responsive cold cathode for bombarding said cathode with said primary particles to produce relatively lower energy secondarily emitted electrons, means for trapping said secondarily emitted electrons within said outer region, means for producing a magnetic field for extending the paths of said electrons beyond the mean free electron path necessary for ionization, means for causing said electrons to flow through said inner region to said plate, means for modulating said electron flow in accordance with the characteristics of said currents to be amplified, and means for collecting said modulated currents.

4. Apparatus for amplifying signal currents comprising a gas-filled-medium amplifier tube having a secondary emission responsive cold cathode, a cathanode, a control grid, and a plate, a first region between said cold cathode and said cathanode and a second region between said cathanode and said plate, a source of primary charged particles adjacent said secondary emission responsive cold cathode for bombarding said cathode with said primary charged particles to produce secondarily emitted electrons, means for trapping said secondarily emitted electrons within said first region and extending the paths of said electrons beyond the mean free electron path necessary for ionization, means for causing said electrons to flow through said second region to said plate, means for modulating said electron flow in accordance with the characteristics of said currents to be amplified, and means for collecting said modulated currents.

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