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The present invention relates to thermionic discharge devices and more particularly to grid controlled gas filled discharge tubes.

An object of the present invention is to improve the operation of gas filled amplifier tubes.

Another object of the present invention is to provide a gas discharge tube having a control grid, or control electrode which maintains control of the anode current at all times.

Another object of the present invention is to provide an amplifier tube in which multiplication of the cathode emission is obtained by ionization of gas within the tube.

Still another object of the present invention is to provide a thermionic discharge device in which the anode circuit is not limited by space charge effects as completely as in heretofore known tubes.

Still another object of the present invention is to provide a gas filled thermionic discharge tube in which the cathode is not subjected to ion bombardment.

Still a further object of the present invention is the provision of a single tube which, under different applied potentials, will operate as an on-off device, or as a linear amplifier.

Heretofore many attempts have been made to develop a gas filled amplifier tube which would have the advantage of multiplication of the cathode emission by ionization of the gas. The heretofore developed tubes, in general, usually included a cathode, either hot or cold, a grid of mesh spaced from the cathode at a large distance, a second grid used as a control element, and any required screen and suppressor grids and an anode, depending upon the characteristic desired. In the operation of these tubes, a glow or arc discharge was obtained between the cathode and the first grid, which was at a positive potential relative to the cathode. The electron current arriving at the first grid or cath-anode was high since it represented the cathode emission multiplied by gas ionization. Most of the electrons proceeded through the first grid, which then acted as the virtual emitter, and the electrons passing from thereon toward the anode were controlled by the second grid as in a conventional vacuum tube. In such tubes it was contemplated that the control grid structure be so arranged that a positive ion sheet was not developed around the grid wires, which would cause them to lose control.

It is believed that these prior attempts to develop a gas filled amplifier tube were unsuccessful for either of the following reasons:

1. Some ionization apparently takes place between the first grid or cath-anode and the plate, and the ions thus produced go to the control grid. The ionization tends to be high since it occurs at a point in the tube where there are a great many electrons present.

2. The grids, or meshes, of previously known tubes, required large diameters and low tolerance spacings, which proved in practice to be extremely difficult to maintain.

A further object, therefore, of the present invention is to provide a gas filled amplifier tube structure which minimizes, or eliminates the difficulties outlined above.

The foregoing objects, and others which may appear from the following detailed description, are attained by providing within a hermetically sealed envelope containing an ionizable gas, a cathode, a first and a second grid, an ion collector, and an anode. The electrons emitted from the cathode are controlled by the first grid and accelerated by the second grid, which is maintained at a positive potential. The accelerated electrons pass into a space between ion collector plates on their way to the anode. The electrons are accelerated toward the anode by the field and ionize gas molecules in transit, thereby producing ions and more electrons. All of the produced electrons progress toward, and are collected by the anode, while the ions, being positively charged, tend to move in the direction toward a lower potential beam deflecting plate, or ion collector. It will be seen that, in the operation of the tube, the electrons from the cathode are controlled first and accelerated, and finally multiplied by gas ionization. Since the grid must maintain control of the initial electron stream, it is desirable that a minimum number of ions be formed in the space between the cathode and accelerator grid. Furthermore, ions produced between the accelerator grid and the anode should not enter the space between the cathode and accelerator grid. This is accomplished in accordance with a feature of the present invention by making the cathode to accelerator grid spacing less than the electron mean free path for the gas density used, or by so proportioning the rate of acceleration that ionization in this space is reduced. The spacing is preferably such that the maximum radial distance of travel of electrons from the cathode through the accelerator grid is less than the electron mean free path, in cases where the accelerator grid is not circular in section. By maintaining the deflector plate at a lower poten-
tial than the accelerator grid, ions produced outside the accelerator grid and returning toward the accelerator will go to the ion collector and will not pass through the accelerator into the cathode-control grid space.

The present invention will be more fully understood by reference to the following detailed description, which is accompanied by a drawing in which:

Figure 1 illustrates in elevation and in partial cross-section an embodiment of the present invention, while

Figure 2 is a plan view of the tube of Figure 1;

Figure 3 is a chart illustrating the relative potential distribution of the electrodes within the tube of Figures 1 and 2 with regard to element spacing;

Figure 4 is a schematic representation of paths which may be followed by electrons and ions within the tube, and

Figure 5 is a plate and accelerator grid current characteristic chart plotted against control grid voltage.

The gas discharge tube shown in Figures 1 and 2 includes a hermetically sealed glass envelope filled at reduced pressure with an ionizable gas. Helium may be used for the gas, since a large mean free path is obtainable at reasonable pressures. Some tubes actually constructed and tested contained, in addition, about one half of one percent of argon gas. A gas pressure of about 250 microns was found to give satisfactory results, though it is not believed to be a critical factor.

Within the envelope is provided a filamentary cathode, a control grid, an accelerator grid, electron beam deflecting and forming plates, and electron collectors or anodes. Plates also serve as ion collectors. Plate serves as an auxiliary anode. While the particular tube shown in Figures 1 and 2 utilizes a filamentary cathode, the use of any type of electron emissive cathode in place of the filamentary cathode, if desired, is contemplated as being within the scope of the present invention. The various electrodes, as described above, are maintained in their relative position within the evacuated envelope by mica spacers. Support for the electrodes and electrical connection to the exterior of the envelope is provided by a suitable number of header pins passing through the glass base of the tube and terminating in connection pins. A conventional lock-in base shell is provided so that the tube may be plugged into a lock-in socket. The spacing between cathode and accelerator grid is arranged to be less than the electron mean free path for the particular gas density used. The electron beam deflecting plates are maintained at a lower potential than accelerator grid so that ions developed in the gas and moving toward less positive regions go to the plates to be collected and do not pass through the accelerator grid into the cathode control grid space. Electrons emitted from cathode are controlled in accordance with potential applied to the first grid and accelerated by the potential applied to accelerator grid. The accelerated electrons pass into the space between the deflecting plates and the inner plates. Inner plates, being at a high positive potential, serve as anodes and attract and further accelerate the electrons. The accelerated electrons ionize gas molecules in their transit through the gas between the accelerator grid and anode at high velocity thereby producing ions and more electrons. All electrons are eventually collected by the anodes, or auxiliary anode. The ions produced, move to plates and are collected there. Plates are externally connected to the cathode. It will be noted that the cathode is not subjected to ion bombardment as in other gas filled tubes; thus a long tube life is obtained.

Thus, it will be seen that the present invention reduces or eliminates the production of ions in the space between the cathode and accelerator grid, and at the same time prevents ions produced in the tube beyond the accelerator grid from entering the cathode-accelerator grid space. The ions produced in the ionization space are collected in a manner which will not adversely affect the operation of the tube.

Now, it is known that the mean free path is the mean distance between collisions with gas molecules. This does not mean that no collisions can take place within this distance. In theory, the fraction of the electrons emitted from the emitter that will not collide with a molecule before traveling a distance is given by

\[ f = e^{-\frac{x}{\lambda}} \]

where \( \lambda \) is the mean free path. The fraction of emitted electrons which does have collisions in going a distance equal to \( x \) centimeters is, then,

\[ 1 - f = 1 - e^{-\frac{x}{\lambda}} \]

If the spacing between emitter and accelerator grid is exactly \( \lambda \), 67% of the emitted electrons would collide with gas molecules before reaching the accelerator. However, if the electron has not been accelerated by the field to a sufficient velocity to have greater than \( E \text{V} \) electron volts of energy when it collides with a gas molecule, the collision will be elastic and no ionization will take place. \( E \text{V} \) is the ionization potential of the gas in electron volts. Collisions in the emitter-accelerator space cannot be entirely eliminated on a space basis alone unless the spacing is zero, an impractical construction. Therefore, the present invention includes the use of either or both of the following factors:

a. If the accelerating potential is sufficient to give the electrons an energy greater than \( E \text{V} \) within the emitter-accelerator space, the maximum radial distance within this space may be made small compared to a mean free path, and the area of the grid wires is made sufficiently large to collect those ions which are produced, without having an ion sheath formed on the wires.

b. If the accelerating potential is lower than \( E \text{V} \) for the gas used, the emitter to accelerator spacing may be larger, since collisions will not result in ionization. However, in this case the anode potential must be higher than \( E \text{V} \) so that electrons will have sufficient energy to ionize beyond the accelerator, and the ion collector must be very effective, since the low potential of the accelerator does not provide as effective a barrier to the ions moving from anode to accelerator. In other words, all ions must be collected before reaching the accelerator, or there must be a region of very low potential on the anode side of the accelerator.

The potential distribution within the tube, without space charge is illustrated in Figure 3, wherein potential values are plotted as ordinates against element spacing as abscissae.
Illustrates the variation in potential distribution. It will be seen that the cathode is at zero potential, and the control grid has a small negative potential applied thereto, while the accelerator grid has a relatively high positive potential, and the ion collector has a potential equal to that of the cathode. Any low potential relative to anode and accelerator electrode may be used. Finally, anodes 20 again have a highly positive potential and are at a comparatively great distance from the remainder of the elements within the tube.

In Figure 4 there is shown a diagrammatic representation of the elements within the tube excepting the present invention with lines 38 and 38 illustrating the electron paths, while cross circles 40 represent produced positive gas ions within the tube. The positive gas ions 40 are attracted to the ion collectors 18, while the electron stream, multiplied at each point of ionization of gas molecules, eventually arrives at the electron collector plates 20 or 24.

Figure 5 is a family of curves illustrating the transfer characteristics of a tube which was actually constructed and tested. A filament voltage of two volts was applied which resulted in a filament current of 90 milliamperes. The plate potential was 250 volts; the accelerator grid potential was varied between 15 and 20 volts; the grid potential was varied from zero to minus 5 volts; a load resistor of 2,000 ohms was provided and a 2,000 ohms series resistor was inserted in the accelerator grid circuit. With 15 volts applied to the accelerator grid, solid curve 55 illustrates the variation in accelerator grid current as the control grid voltage is varied from zero to minus 5 volts, while solid curve 52 illustrates the variation in plate current for a similar control grid voltage variation for an accelerator electrode potential of 15 volts. When the accelerator electrode potential is increased to 20 volts, the variation in accelerator grid current is illustrated by dotted curve 54, while the anode current follows dotted line 55. It will be seen that for a range of control grid voltage running from zero to about minus 3 volts, the variation in anode current is substantially linear.

It should further be noted that the curves terminate abruptly at about minus 5 on the grid voltage scale. Above this potential the ionization seems to cease, and the tube cuts off abruptly.

Thus, in a single tube it is possible to obtain an off-on action over one range of applied potentials, and a linear amplification characteristic over another range of potentials.

While I have particularly shown and described an embodiment of the present invention, it should be clearly understood that my invention is not limited thereto but that modifications within the scope of the invention may be made.

What is claimed is:

1. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid and an accelerating grid surrounding said cathode, an electron collecting anode, and an ion collector electrode adjacent the electron path between said cathode and said anode.

2. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, and electron emitting cathode, a control grid and an accelerating grid surrounding said cathode, an electron collecting anode, and an ion collector electrode adjacent the path of electrons progressing from said cathode to said anode, said collector electrode being arranged to collect ions liberated by said electron stream, between said accelerating grid and said anode.

3. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid and an accelerating grid surrounding said cathode, an electron collecting anode, and an ion collector electrode adjacent the path of electrons progressing from said cathode to said anode, said collector electrode being arranged to collect ions liberated by said electron stream, between said accelerating grid and said anode, the maximum radial dimension of said accelerating grid being less than the electron mean free path of said ionizable gas whereby substantially no ionization takes place within said accelerating grid.

4. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid and an accelerating grid surrounding said cathode, an electron collecting anode, and an ion collector electrode adjacent the path of electrons progressing from said cathode to said anode, said collector electrode being arranged to collect ions liberated by said electron stream, between said accelerating grid and said anode, the maximum radial dimension of said accelerating grid being less than the electron mean free path of said ionizable gas whereby substantially no ionization takes place within the hermetically sealed grid-cathode space.

5. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid, and an accelerating grid closely adjacent said cathode, an electron collecting anode at a substantial distance from said cathode, an electron beam deflecting electrode for causing a beam of electrons from said cathode to follow an indirect path to said anode, said beam causing ionization of the gas along said path, the electrons caused by said ionization also going to said anode, said deflecting electrode being so energized as to collect gas ions liberated by said beam.

6. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid, and an accelerating grid closely adjacent said cathode, an electron collecting anode at a substantial distance from said cathode, an electron beam deflecting electrode for causing a beam of electrons from said cathode to follow an indirect path to said anode, said beam causing ionization of the gas along said path, the electrons caused by said ionization also going to said anode, said deflecting electrode being so energized as to collect gas ions liberated by said beam.

7. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid, and an accelerating grid coaxially surrounding said cathode, an electron collecting anode at a substantial distance from said accelerating grid, said cathode being adapted to generate a beam of electrons to impinge upon said anode, said beam causing ionization of gas in the space between said accelerating grid and said anode.

8. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting
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7 cathode, a control grid and an accelerating grid coaxially surrounding said cathode, a number of electron collecting anodes at a substantial distance from said accelerating grid, means for forming a beam of electrons from said cathode, means for causing said beam to impinge on said anodes, said beam causing ionization of gas in the space between said accelerating grid and said anodes.

9. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid and an accelerating grid adjacent said cathode, an electron collecting anode at a substantial distance from said accelerating grid, means for forming a beam of electrons from said cathode, means for causing said beam to impinge on said anode, said beam causing ionization of gas in the space between said accelerating grid and said anode, said last mentioned means serving to collect ions in said space.

10. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid and an accelerating grid coaxially surrounding said cathode, a number of electron collecting anodes at a substantial distance from said accelerating grid, means for forming a beam of electrons from said cathode, means for causing said beam to impinge on said anodes, said beam causing ionization of gas in the space between said accelerating grid and said anodes, said last mentioned means serving to collect ions in said space.

11. A grid controlled gas discharge tube including within a hermetically sealed envelope containing an ionizable gas, an electron emitting cathode, a control grid and an accelerating grid surrounding said cathode, an electron collecting anode, and an ion collector electrode adjacent the path of electrons progressing from said cathode to said anode, said collector electrode being arranged to collect ions liberated by said electron stream, between said accelerating grid and said anode, the maximum radial dimension of said accelerating grid being less than the electron mean free path of said ionizable gas whereby substantially no ionization takes place within said accelerating grid, the conductors of said accelerating grid having such area as to collect any ions which may be formed, without forming an ion sheath on said conductors.

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