April 27, 1954 W. C. MILLIGAN 2,677,070

COATED GRID TUBE

Filed May 4, 1950 2 Sheets-Sheet 1

Fig. 1

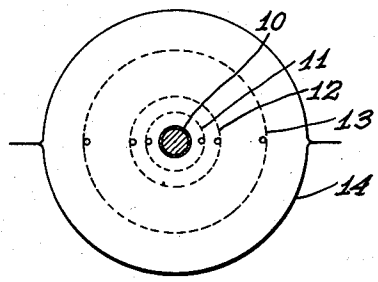



Fig. 2

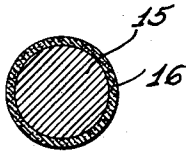



Fig. 3

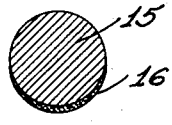
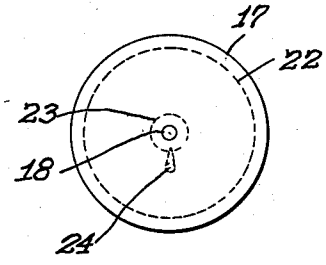



Fig. 4




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Fig. 5

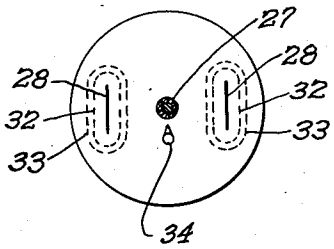



Fig. 6

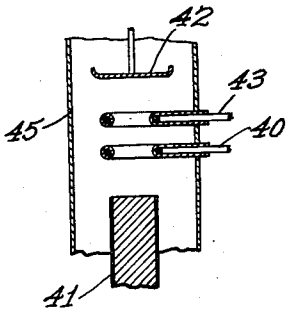
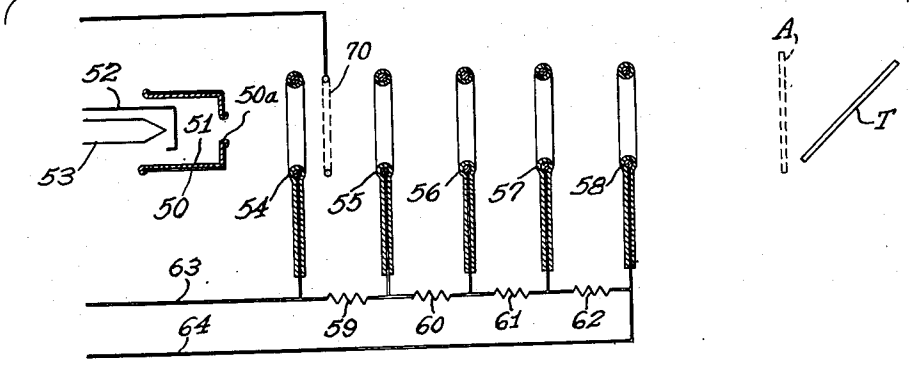



Fig. 7




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# UNITED STATES PATENT OFFICE

2,677,070

## COATED GRID TUBE

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Application May 4, 1950, Serial No. 160,060

9 Claims. (Cl. 313—195)

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The present invention relates to an electron tube, and particularly, to a grid structure for electron tubes. The grid structure of the present invention has many applications such, for example, as control grids in vacuum or gas amplifier tubes, transmitting tubes, as starting electrodes in heated or cold cathode gas tubes, photo-electric cells, as electron-accelerator grids in cathode ray tube structures, X-ray tubes, and high frequency oscillators.

It has long been recognized that it would be desirable to operate control grids in electron tubes at positive potentials since the plate current and, hence, the power output of the tube would be increased. It has heretofore been considered impractical, however, to provide circuits which utilize substantial positive grid voltages on the control grid because a control grid is normally a fine wire coil or mesh. Any substantial amount of grid current drawn as a result of driving the control grid positive could easily destroy the grid, or introduce objectionable noise into the circuit.

Within certain limits, operating the control grid at a positive potential will increase the flow of plate current. Beyond that limit, an increase in the positive potential applied to the grid causes a decrease in the plate current by diverting too high a proportion of the electron stream from the plate. This diversion of electrons from the plate to the grid results in a proportional loss of plate current, and consequently, a loss in over-all tube efficiency. If the grid current could be reduced to a small fraction of what it would normally be for a given voltage, the performance characteristics of the tube would be radically altered with respect to its over-all performance.

Suggestions have been made by prior workers in the field to prevent the grid wires from absorbing current when the grid wires are positively charged. One such suggestion has been to completely coat the grid wires with an extremely good insulating substance, for example, a heat-resistant glass composition such as Pyrex glass. When grid wires are insulated with such good insulators, electrons will accumulate on the outer surface of the insulated material when the grid wires have a positive potential applied. The accumulated charges cannot be rapidly removed from the structure of the coated grid, since the positive voltage beneath the insulation is sufficient to hold the electrons on the surface of the coated grid and prevent their migration to the plate. A capacitive effect is then created, so that the charge can only be dissipated through leakage off the coated surface. It has been thought that

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any such insulating film must have a very high insulation value in order to prevent the film from puncture which would cause a concentration of current at the point of puncture. The effects of such puncture would be cumulative in that the localized region of high current flow would give rise to a greater concentration of heat at that point, and the increased heat would in turn reduce the effectiveness of the insulation near the punctured area, and thus increase the path of the concentrated current.

However, if materials of very high insulation value are used, any accumulated charges on the surface of the coated grid are not likely to permeate the insulating film and reach the positive grid wires beneath. Thus, the leakage rate from the surface of the coated grid would be inversely proportional to the degree of insulation afforded by the coating. Consequently, if the coating has very good insulating qualities, there will be a considerable time lag for the grid to establish equilibrium with the positive charges on the grid wires. This results in a correspondingly slow grid response in controlling the current flow. It has been observed that when using a coating of Pyrex of approximately .005 inch in thickness, the accumulated charges stay on the surface for approximately one hour and prevent any flow of current to the plate during that period. A substantial increase in plate voltage fails to give any plate current. The same is true when the positive grid voltage was increased considerably.

When the magnitude of the positive voltage impressed on the grid is decreased, a small degree of control of plate current was possible, but the response is very sluggish.

A further attempt to solve the problem of paralysis of the insulated grid was made by insulating only a small portion of the grid wire, that is, only the portion of the grid which faces the cathode. However, this modification was unsuccessful because the insulated film on the coated portion of the grid surface operated under the same conditions as the completely insulated grid. The portion of the grid facing the cathode intercepts and holds the greatest number of electrons, and any electrons not striking the grid facing continue on toward the plate. Hence, the charges that accumulate on the side of the grid which faces the cathode are the same as would occur as if the grid were completely insulated.

By coating only one surface of the grid wire, and leaving the rear portion of the grid uncoated, it was possible to neutralize partially the charge accumulation on the front portion of the grid,

but this modification was still insufficient to prevent the sluggish action of the tube. The small gain in efficiency was probably due to the fact that some of the charges accumulating on the front part of the grid could gradually leak to the back surface and be more easily discharged onto the exposed surface of the grid. Any charges leaking to the rear of the partially covered grid might be instantly absorbed by the grid surface, but for most purposes, the rate of migration of the charges was not sufficient to prevent the sluggish action.

With the foregoing in mind, an object of the present invention is to provide a coated grid structure which can effectively dissipate accumulated charges, and permit operation of the grid at relatively high positive potentials.

Another object of the present invention is to provide a coated grid structure upon which a high positive potential can be applied without drawing a substantial amount of grid current.

Still another object of the present invention is to provide an electron tube assembly with a coated grid structure which will increase the over-all efficiency of the tube.

Yet another object of the present invention is to provide a coated control grid which may be used as an electron accelerator without excessive current consumption.

Other objects and features of the present invention will be apparent to those skilled in the art from the following description and the appended claims.

One of the main features of the present invention consists in providing a coating for a grid structure, in which the grid is covered completely or partially with a semi-conductor or high resistance material which remains integrally bonded to the underlying grid at temperatures substantially above the operating temperature of the tube. The resistivity of the material at the operating temperature of the tube is greater than the resistivity of the metallic grid surface but less than the resistivity of a conventional insulating material, such as glass. I have found that by covering a control grid with such material, performance characteristics can be achieved which are distinct from those of any other known type of tube.

The manner in which the coating is believed to function and operate will now be described. When the coated grid is operated at a positive potential, the electrons attracted to the portion of the grid which faces the cathode can be dissipated or absorbed by the positive grid wires in two manners. First, a major portion of the charges on the surface will be conducted through the thin resistance film to the grid wire surface facing the cathode. Secondly, any remaining charges not absorbed by the film can be quickly dissipated by the conductive coating at the rear of the grid wires which attracts the charges along the conducting coated surface to the rear of the grid wires and then through the conductive coating into the positive grid wires. Some of the slower electrons can be diverted in their path sufficiently to cause them to strike the rear portion of the grid surface, but this represents only a relatively small proportion of the total electron flow in the tube.

I have found that a grid coated in this manner has the property of holding a large quantity of electrons in very close proximity to the grid while absorbing only a very small percentage of the electrons. The positive field in the region of the grid apparently captures and holds the electrons without absorbing them by forcing the electrons to deviate from their normal path toward the plate and curve back toward the grid. If the plate voltage is sufficiently low, the electrons will apparently keep circling about the grid due to their initial velocity, and will be repelled from the cathode due to the formation of the negatively charged electron cloud in the region of the cathode.

If the proper resistance value is chosen for the coating, there will be no time lag in the grid control even at fairly high frequencies, since any excess charges can be quickly absorbed through the coating film to the underlying positive grid wires and also around the conducting surface to the rear of the grid wires.

In the operation of the tube, an increase in the positive grid voltage will cause a corresponding increase in both the plate and grid current. The amount of charges accumulated on the surface will not be excessive since the increase in positive voltage on the grid will also increase the number of electrons drawn to the grid surface. If a relatively constant positive grid potential is impressed on the grid, no excess charge effects will be observed because the plate current will remain at a given value determined by the plate and grid voltages. The amount of grid current drawn will also stabilize at some value in proportion to the grid voltage and the resistance of the coating.

When the value of the positive voltage applied to the grid decreases, the resistance of the film should be sufficiently low to permit rapid dissipation of any excess electrons attracted to the grid at the peak positive value but not absorbed before the positive grid voltage begins to decrease. Consequently, the determining factor in choosing the proper resistance for the grid coating will be determined primarily by the frequency of the voltage impressed upon the grid. The higher the frequency, the lower the resistance should be to permit dissipation of residual charges on the grid surface as the voltage decreases. Other factors which will determine the degree of resistance to be had in the resistive coating are the total grid area to be covered by the film, the distance from the grid to the cathode, and the configuration of the grid with respect to other grids in the tube. Where the peak grid voltage to be impressed upon the tube is relatively low, the resistance of the coating likewise should be low to prevent any lag effects due to charge accumulation. However, the resistance should not be too low as the grid current drawn will be increased, thus decreasing the over-all tube efficiency. Therefore, the choice of proper resistance is necessarily a compromise at a value which will permit rapid dissipation of charges on the grid without causing an excessive amount of grid current flow.

As an empirical guide, I have found that the film resistance should be sufficient to give a grid current, at the peak of the positive voltage to be used, of approximately 1% to 5% of the total plate current.

Obviously less than 1% or more than 5% of the total plate current can be consumed by the positive control grid and still give excellent efficiency; however, in general, the 1% to 5% range will be found suitable for most purposes.

For most tube applications, the total coated area of the grid will have a resistance value in the range of .05 to 20 megohms. A majority of

tubes can be effectively coated with films having a resistance from 0.1 to approximately 1 megohm. Small radio frequency receiver tubes will require a somewhat larger resistance value, such, for example, as on the order of 1 to 10 megohms, and high power tubes such as transmitting tubes will use resistances in the range of several megohms. Audio frequency or modulation tubes will have resistance coatings in the lower end of the given range, on the order of .1 megohm or less.

The nature of the coating composition will, of course, depend on the resistance value desired, as previously discussed. Where the tube is to operate at a fairly high heat and a high resistance is desired, I have found that one of the desirable materials to use is a vitreous type enamel on the grid. This type of enamel is commonly used for protecting corrodable materials and normally consists of vitrefied calcium silicates. A large variety of materials may be used in the preparation of the vitreous enamels, and their preparation is well known in the art. Normally, the vitreous enamel compositions are prepared by fusing together feldspar, borax, quartz, soda ash, fluorides, and a suitable opacifier. The resulting molten glass is then poured into a stream of water to form a frit which is ball-milled either wet or dry and then applied to the wire by dipping, spraying, or dusting.

The thermal expansion characteristics of the vitreous enamel may be varied to very closely approximate the expansion characteristics of the metal coated. A unique characteristic of the vitreous enamel type coating is the fact that it has a negative temperature coefficient of resistance, i. e., the higher the temperature the lower the resistance. At room temperature, this ceramic material is a very good insulator, but at the operating temperature of the tube, when placed in close proximity to the highly heated cathode, the resistance may be decreased into a range of from about 10 to 20 megohms.

The powdered ceramic materials should be carefully screened to eliminate any large size impurities that might cause current concentration at a localized area. The ceramic material should also be ground to a very fine state of subdivision in order to provide a very thin coating. It is preferable to coat the grid structure after thoroughly cleaning the same. The thickness of the coating applied should be as thin as possible, and it is desirable in tubes which are not required to have a high power rating, not to exceed a coating thickness of .005 inch. In such tubes, the coating is preferably of a thickness between .001 and .002 inch. It will be appreciated that the thickness of the coating employed will very often be determined by the geometry of the tube elements.

However, the coating applied may have a thickness less than .001 or greater than .005 inch if the necessary tube design, type of insulating film, and materials used would require or permit wider ranges than that given. Some types of materials, if too thick, would not adequately serve their purpose, depending on their composition, resistance, and insulator characteristics; conversely, the thicker the film, the more difficult it is to apply the coating smoothly and with uniform thickness. Furthermore, it should be obvious that the thinner the film, the less chance there would be for undue time lag effects in the plate circuit from charge accumulations and excessively thick films.

After applying the ceramic coating, the grid is preferably fired in an atmosphere of hydrogen to liberate any occluded gases, and thereby provide a more coherent coating.

For lower resistance films, a material having a resistivity of only a few hundred times as great as the resistance of the grid wires can be employed. I have found that a class of mixed oxides known as the spinels are especially effective for this purpose. These spinels may be represented by the general chemical formula $XOY_2O_3$ in which X is a bivalent metal and Y a trivalent metal, and X and Y may be the same metal. The preferred compound falling within the scope of the invention is ferroso-ferric oxide, $Fe_3O_4$. Other crystals which have the same crystal structure as $Fe_3O_4$ may also be employed.

One of the class of spinels which find particular use in the practice of the present invention are the mixed ferrites such as zinc ferrite, magnesium ferrite, copper ferrite, and the like. For a description of the properties of the mixed ferrite crystals, as well as modes of their preparation, reference is made to United States Patents Nos. 2,452,529, 2,452,530, and 2,452,531, issued to J. L. Snoek.

In addition to the ferrites, other spinel compounds may be employed. For example, compounds such as the magnesium aluminum spinel, $MgOAl_2O_3$, the magnesium chromium spinel, $MgOCr_2O_3$, and the zinc chromium spinel, $ZnOCr_2O_3$, or combinations thereof may be used. As in the case of the vitreous enamel coating, the coating with such metallic spinels should preferably not exceed .005 inch and will normally be on the order of .001 to .002 inch. These and other types of coatings, whose compositions and effectiveness would not be damaged by so doing, may be applied to the grid by vacuum deposition, or by deposition from an inert gaseous carrier.

In addition to spraying, dipping, vacuum coating, etc., of the grid structure, it may also be found deisrable to use high resistance coatings in an electrolytic bath or high resistance films such as oxides, of which anodizing is superior. For instance, if it is deisrable to use a metal which can be anodized, such as aluminum or aluminum plated on a metal grid, a tough and tenacious film of oxide may be easily and cheaply applied by simply regulating the amount of voltage used in a suitable bath. The higher the voltage used, the higher the resistance and thickness of the resulting film. Consequently, this method can also provide simple and inexpensive means of regulating resistance to the protective film by how much voltage is used in the treating bath.

Although examples have been given as to what might be useful, it should be understood that the selection of materials to be used, in general, will belong to the semi-conductor class of materials, of which, of course, there are hundreds. The "semi-conductors" represent a group of materials having unique resistance characteristics. These materials are not just high resistance compositions, but are basically different from high resistance metals. The resistivity of the semi-conductors ranges between the resistivities of metals and insulators, and usually ranges from about $10^2$ ohm-cm. to $10^9$ ohm-cm. However, the range of the desirable ones is not that extensive; but, nevertheless, there are quite a number of semiconductors and other materials which would serve the purpose intended, provided just enough resistance is available to prevent charge accumulation on the surface of whatever coating material is utilized. The selected one should also not

consume any more current than is actually necessary to serve the purposes intended as, otherwise, it would represent useless waste of energy in the tube with a resultant loss of a proportional over-all efficiency. It is also possible to mold or otherwise fabricate grids of such composition that desired resistance from surface to interior of the grid can be obtained which will serve the same purpose as coating a standard grid construction. As a further example of materials that may serve the purpose desired, high resistance carbonaceous films may be used to advantage wherever the resultant resistance film will adequately serve the purposes of this invention. Therefore, it is not the purpose of this invention to limit the coating material or method of application desired specifically to those outlined but, rather, those outlined are suggested means of accomplishing the coating of the structure with a suitable resistive coating of any material available which will give adequate performance at a reasonable cost consistant with ease of application.

The coated grids of the present invention will find use in many different types of electron tube applications. In the drawings, by way of example, I have illustrated several embodiments of the present invention.

Figure 1 is a transverse cross-sectional view of a conventional pentode structure of a high vacuum tube with the glass envelope removed;

Figure 2 is a transverse cross-sectional view of a grid wire coated completely with the coating of the present invention;

Figure 3 illustrates a modified form of coating in which the coating material extends only partially about the periphery of the grid wire;

Figure 4 is a transverse cross-sectional view of a cold cathode gas amplifier tube with a starter mechanism;

Figure 5 is a transverse cross-sectional view of another form of a cold cathode gas amplifier arranged for push-pull operation;

Figure 6 is a transverse cross-sectional view of a thyratron tube with two coated grids; and

Figure 7 is a cross-sectional view of an accelerating grid structure embodying the principles of the present invention.

The pentode structure shown in Figure 1 includes a centrally disposed cathod 10 capable of emitting electrons upon reaching a predetermined temperature. Surrounding the cathode is a coated control grid 11 in the form of a wire mesh. A screen grid 12 and a suppressor grid 13 are disposed concentrically with the cathode 10 between the control grid 11 and the metallic plate 14.

The structure of the coated control grid 11 is more clearly illustrated in Figure 2, and a modified form thereof is shown in Figure 3. In Figure 2, a grid wire 15 is shown as completely surrounded by a relatively thin coating or film 16 comprising one of the coating materials as previously discussed. In Figure 3, the grid wire 15 is shown only partially surrounded by the coating 16, it being understood that the coated surface will be arranged to face the cathode of the tube.

The use of multiple grids, both coated and uncoated combinations and either equally or unequally spaced grids, can be used to provide an extremely broad latitude of design factors to obtain an unusually wide variety of tube designs of very outstanding performance characteristics which have not been possible to obtain in any type of tube known to me.

In normal tube design the power-handling capacity of a plate of a given area is determined mainly by the total average current and the plate voltage. The higher the plate voltage, the larger the plate area must be to dissipate the heat generated by correspondingly higher speed electrons striking its surfaces and thereby dissipating a large amount of heat, which is considered a definite tube loss since the energy lost in heat serves no useful function. Whereas, in a tube of the present invention, one or more of the grids near the plate can serve a dual function of reducing space charge and at the same time preventing the electrons to the plate from gaining excessive speed, due to the speed limiting effects of these positive coated grids when operated for that object. Therefore, the positive grids can both attract, and at the same time, limit the speed of the electrons that they, or the plate, attract toward the plate, so that when they come into the major field of influence of the positive plate, they do not have enough remaining transit time to gain appreciable amounts of velocity. This reduction in speed proportionally reduces the kinetic energy by which electrons can strike the plate area, which means much higher power handling capacity, without sacrificing the advantage of high voltage on the plate circuit. Consequently, this is somewhat the same effect as if the plate voltage remained the same or could be actually increased for a given plate area and obtain greater amounts of current to the plate without excessive heat losses in a manner somewhat similar to reducing the tube drop or internal resistance of the tube to a much lower value.

To get maximum benefit from an arrangement of this sort, the positive grids should be spaced apart to only that distance which would correspond to a given tube drop desired in the tube so that only a relatively short distance would be required for the electron to pass through the field of influence of one grid into that of another. Thus, by successive stages of nearby grids, the electrons can be easily and efficiently removed by the first grid surrounding the cathode and, in effect, pass them along to succeeding stages which are spaced together close enough to efficiently attract and pass on to successive grids the electrons initially started from the cathode by the first grid. If these relatively close spaced grids are continued on up until the last one is close enough to the plate to pass effectively its current load on to the plate with a minimum of space separation, the over-all tube drop, which is normally very high, can be reduced to a relatively low figure and at the same time maintain a very high voltage on the plate if desired.

Although normally the high plate voltage would exert enough acceleration effects on the electron to make it gain high speed, in the above arrangement, the positive field of the successive grids would have enough influence on the electron in their passage to the plate to override the effects of the plate to a surprising extent due simply to the grids being physically and electrostatically nearer to the electrons than the plate until they are very close to the plate. High voltage in the plate circuit enables high wattage to be obtained at relatively low current values. However, if a high voltage could be maintained and the current value considerably increased without attendant heat dissipation losses in the plate circuit, much higher powered tubes can be built, by having the important advantage of being considerably smaller in size and costliness to build.

The positive grids 12 and 13 also would serve the purpose of reducing internal capacitance of

the control grid to plate elements, as is done in standard tube practice but with considerably greater efficiency and the rather obvious advantages as previously noted.

Figure 4 illustrates an embodiment of the present invention utilizing a cold cathode type of gas-filled tube suitable for amplifier and other purposes. For instance, the tube can be constructed with a cold cathode element 17, a positive anode 18, and a starter element 24 in conjunction with a control grid 22. In this arrangement, starter electrode 24 can be a resistive coated tube element to eliminate excess current drain when the ionization is initiated. The tube also contains an accelerator grid 23 disposed between control grid 22 and anode 18. Grid 22 may be any suitable type of wire wound grid element or wire mesh grid element, etc., which has a suitable resistive coating so that a suitable positive voltage can be applied to control grid 22 without setting up an excessive cold cathode discharge between the control grid element 22 and negative cathode element 17. In this manner, any current first initiated between starter element 24 and the anode 18 will then cause current to flow from cathode 17 to anode 18. Thereupon, control grid 22 can be used to control the current flow between cathode 17 and anode 18 by means of a positive or negative potential impressed on grid 22. If a positive potential is applied to control grid 22, any electron current flow from the cathode 17 to the anode 18 would be intercepted by control grid 22 in the manner described in Figure 1 with the exception that the controlling conditions would be occurring in an ionized atmosphere instead of in a vacuum. The combination of ionization and a coated grid 22 having a positive voltage impressed on it sets up very much different conditions of grid control than that found in ionized atmospheres which contain normal negative grids. I have found that a coated control grid will act very efficiently in a light or heavily ionized atmosphere with remarkably good control which has proved to be surprisingly linear in its control ability over the plate current. This type of positive coated grid construction is not subject to the usual negative grid ionization paralysis effect, in an ionized atmosphere, for the reason that the control potential is positive and, therefore, cannot attract a paralyzing ionized sheath in a manner similar to a negative potential grid but, rather, effectively dissipates any tendency of such paralysis sheath action due to the positive potential on the grid. The positive electrostatic field of the grid will repel any positively charged ionization near its vicinity. Therefore, it can attract electrons very efficiently without any paralysis effect whatsoever from plasma sheath conditions, which normally causes paralysis of a negative grid. Since this control grid will draw only a small proportion of the current it controls, it is, therefore, quite simple to control the current flow between cathode 17 and anode 18 by the superior influence of control grid 22, which in a manner previously explained in Figure 1 can accelerate, decelerate, or capture electrons passing through its vicinity. At first, it may not be apparent as to why this positive grid can effectively override the fields of attraction exerted by positive ionization in the plasma sheath and anode 18. The major conditions favor this control action in spite of presence of ionization. First, in this particular embodiment, control grid 22 is relatively close to cathode 17 and can thereby influence the passage of electrons at relatively low voltage since it is much nearer physically and electrostatically to the electrons leaving cathode 17. Second, if required, the voltage on grid 22 can be raised much higher than the positive voltage on anode 18 without drawing excessive current and thereby insure, regardless of conditions or amount of current flow, that control grid 22 could exert a much greater positive field of influence on the electrons attempting to reach the anode 18.

It should, therefore, be evident that the positive control grid 22 can act in a very efficient manner to effectively control current without any difficulty arising from plasma sheath effects and, at the same time, provide a very effective means of gaining considerable tube drop between cathode 17 and anode 18 which increases the over-all efficiency of the tube by providing more current at lower voltages in a very simple manner.

In respect to Figure 4, the starter circuit could be turned off and full control and operation of the tube be continued provided the tube is never driven down low enough for complete shut off of current. Therefore, leaving a minimum amount of plate current in which ionization could be maintained would allow the starter circuit, if desired, to be shut off in the interest of current economy and efficiency.

Figure 5 illustrates another embodiment of this invention wherein the resistance coated control element is utilized to provide a gas amplifier of different construction to that shown in Figure 4. The drawing illustrates a push-pull arrangement, but a description of one section will suffice to illustrate the arrangement. In this instance, cathode 27 is combined with a starter element 34 to initiate ionization which will then permit current flow between cathode 27 and a positive anode 28 which, in turn, is surrounded by a control grid 32 which is also surrounded by a screen grid 33. The operation of this tube is quite similar to that of Figure 4, in that current is designed to flow between cathode 27 and anode 28, in the process of which positive control grid 32, which has a resistive coating, can be used to control current to the plate. Screen grid 33 should also be coated, although it can operate without such a coating; but if coated, would, of course, reduce current drain to screen grid 33 for a given voltage. In addition, coated screen grid 33 will enable the use of high enough positive voltage from the screen circuit to assist the control action of control grid 32 and yet draw relatively little current. If screen grid 33 is operated at a sufficient voltage and current drain to sustain ionization in the tube, regardless of the current flow to the anode 28, it will be found that current can be completely shut off from anode 28, by grid 32, without extinguishing the arc in the tube, which would permit the starter circuit to be shut off, once ionization has been obtained in the interest of current economy. The use of screen grid 33 in the manner described has other advantages such as permitting a higher frequency range to be used, since screen grid 33 would maintain ionization to within fairly close spacing of the anode 28. This, of course, eliminates any appreciable time lag caused by ionization and deionization due to current being completely shut off from the plate circuit without ionization being maintained by screen grid 33 or starter 34.

Selection of the proper positive voltage to be used on screen grid 33 can greatly assist the operation of control grid 32, in respect to lowering the requirement of how much voltage would be

needed on control grid 32 and also increase its sensitivity by operating screen grid 33 near such a critical point that control grid 32 can easily attract or prevent electrons from reaching the anode. Of course, another positively or negatively operated grid can be used around the cathode 27 either in conjunction with the control grid 32 and screen grid 33 or without them. The extreme ends of the positive grids, including the connecting leads, should be completely insulated or otherwise current flow to these exposed ends would upset the control grid operation by excess current drain and excess heat. This would not be necessary if the ionization can be confined to the grid operating area, or if the starter and cathode leads can be insulated at the extreme ends. The latter will work properly, however, only if a shield is used all around the elements, or if an enclosed circular plate is used such as in Figure 4.

In the foregoing gas amplifier examples, it is intended to be understood by those skilled in the art that proper means should be provided, such as mica spacers, in close enough vicinity of the plate area to prevent ionization from by-passing the grid when in operation. In addition, an insulating means or a metallic sleeve should be provided around the lower extremity of the anode lead or support which is not under the control influence of the control grid. This is needed in order to prevent current flow to this portion of the anode assembly. Generally, a glass sleeve will suffice, but a metal or screen cylinder which does not physically touch the anode can also be utilized, which may or may not be grounded but preferably in most circumstances should be grounded.

Figure 6 is a vertical cross-sectional view of a suitable thyratron structure embodying two coated grid eelctrodes of the present invention. A grid 40 disposed between a cathode 41 and an anode 42 can be used to provide a constant negative bias at any chosen potential in respect to anode 42, in order that grid 40 would thereby electrostatically predetermine the negative or positive starting voltage characteristics of anode 42, when used in conjunction with a second grid 43 between the grid 40 and the anode 42. The grids 40 and 43 are supported through a conventional shield 45. By this means, a given thyratron structure can be used as a negative or positive starting thyratron, in respect to any given plate voltage of anode 42, entirely at the will of the operator of such a tube, instead of its being determined only by structural features of the thyratron tube, which, of course, could not be changed once the tube has been built.

If the grid 40 has been set at some negative value to prevent anode 42 from initiating the arc at some given voltage such as 500 volts, no current will flow due to the negative electrostatic repelling influence of the grid 40 on electrons in the vicinity of cathode 41. When the arc is desired to be struck, it can be easily, quickly, and efficiently accomplished by applying a sufficiently positive voltage to the grid 43. If it is desired to operate a tube with twice as high a plate voltage, such as 1,000 volts, without triggering the tube, it is only necessary then to raise the the negative grid voltage of grid 40 enough to prevent such ignition. The grid 43 can then be used to initiate the arc in the previous manner by applying a sufficiently high positive voltage to this grid.

Regarding Figure 6, it should be understood that the lead wire to the grid upon passing through the shield should also be coated, preferably up to the point where it passes through the glass bulb enclosing all the tube elements. In this manner, excess current flow to an uncovered portion of the grid circuit would be prevented from occurring over a path it would not be desired for the current to flow, inasmuch as it would seriously impair the control characteristics desired in a tube of this nature.

Figure 7 is another example of the unusual opportunities for the design and construction of electronic tubes which are of much greater efficiency than heretofore possible. Specifically, Figure 7 illustrates schematically an X-ray tube, but it will be appreciated that similar arrangements may be incorporated in other types of tubes using accelerator grid circuits.

As one example, a control grid 50 has a resistive coating 51. The control grid 50 is in the shape of a hollow cylinder having an aperature 50a through which electrons liberated at a cathode 52 by the heat of the filament 53 may escape when control grid 50 has a sufficiently high positive voltage. These electrons can then be attracted to the center portion of the first circular accelerating grid 54, provided it has a higher positive voltage than the control grid 50. When these high speed electrons arrive at the center of grid 54, they are, in turn, attracted to and receive a higher acceleration rate at the second accelerating grid 55, which should have a higher positive voltage than grid 54.

In like manner, electrons will be efficiently and progressively accelerated by succeeding circular positive grids 56, 57 and 58, provided that each has a sufficiently high voltage to increase progressively the acceleration rate. Progressively higher voltage beginning at grid 54 and ascending to grid 58 can be accomplished in a very simple manner with only two outside leads through the tube by means of a series of dropping resistors 59, 60, 61 and 62. The input voltage for these five accelerator grids can be introduced by a pair of leads 63 and 64. It is understood, of course, that each of these accelerator grids would have the proper type of resistive coating.

Electrons progressively accelerated up to and through grid 58 can be made to strike an inclined target, such as T, with considerable force if target T has the proper amount of anode voltage. By the above means, it should now be apparent that very high acceleration forces can be applied to a dense stream of electrons which can be made to strike an inclined target T for the production of either hard or soft X-rays which would have a penetration power equal to the X-rays emitted from a target surface requiring much higher voltage than the present invention.

In this manner, considerable efficiency can be obtained in a more compact length and at less accelerating potentials than has heretofore been possible.

An additional grid 70, shown in dotted lines, may be used as a focusing device without causing an electron speed reduction simply by placing it preferably in line or parallel to the coated grid structures. It would also be preferable for the grid 70 to be of smaller diameter than the grid 54. By this simple means, no loss in efficiency would occur from any repulsion effect of the grid 70 when operated as a negative grid in respect to a retarding effect on the electron

velocity passing through its vicinity. Obviously, similarly constructed grids may be placed in the same position next to the other positive accelerating grids. Grid 70 could then serve as effective means of determining the beam size of the electron stream passing through each accelerating grid and also when the beam diverges from the last accelerator grid toward the target.

It will be apparent that numerous other variations can be set up or designed to take full advantage of the unusual properties provided by the constructional features of the structure shown in Figure 7.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

I claim as my invention:

1. In a cold cathode gas tube having a cathode capable of emitting electrons and a plate for receiving electrons emitted from said cathode, said plate and cathode being disposed in an atmosphere of ionizable gas, a starting electrode having a thin coating of a material having a resistivity at the operating temperature of the tube greater than the resistivity of the uncoated electrode, but insufficient to cause an appreciable time lag in dissipating charges from the grid, the resistivity of said coating being in the range from .05 to 20 megohms.

2. In an electron discharge device including a cathode capable of emitting electrons and an anode for receiving said electrons, the improvement which comprises an accelerating anode for accelerating electrons in passage between said cathode and said anode, said electrode having a coating thereon having a resistivity greater than that of the uncoated electrode but insufficient to cause an appreciable time lag in dissipating charges on said electrode, the resistivity of said coating being in the range from .05 to 20 megohms.

3. A cold cathode gas tube comprising a cathode, an anode arranged to receive electrons from said cathode, a grid disposed between said cathode and said anode for directing current flow therebetween, said cathode, anode and grid being disposed in an ionizable gas atmosphere, said grid having a coating thereon having an appreciable resistance value, said resistance value being below that which would cause an appreciable time lag in dissipating charges from the grid, said resistance value being in the range from .05 to 20 megohms.

4. A cold cathode gas tube comprising a cathode, an anode arranged to receive electrons from said cathode, a pair of grids disposed between said cathode and said anode for directing current flow therebetween, said cathode, anode, and grids being disposed in an ionizable gas atmosphere, at least one of said grids having a coating thereon of an appreciable resistance value, said resistance value being below that which would cause an appreciable time lag in dissipating charges from the grid, and being in the range from .05 to 20 megohms.

5. In a cold cathode gas tube including a cathode, and an anode arranged to receive electrons from said cathode, both said anode and cathode being disposed in an atmosphere of an ionizable gas, a decelerating grid disposed between said anode and cathode having a coating thereon of material having a substantial electrical resistance in the range from .05 to 20 megohms.

6. In an electron tube, an electron-emitting cathode, an anode, a control electrode of electrically conductive material interposed between said cathode and said anode and at least partially coated with a coating of resistance material, the resistance of said resistance material being at least a few hundred times that of said conductive material and low enough to prevent any appreciable charge accumulation on said control electrode.

7. In an electron tube, an electron-emitting cathode, an anode, a control electrode of electrically conductive material interposed between said cathode and said anode and at least partially coated with a coating of resistance material, the resistance of said coating being higher than that of said control electrode and low enough to prevent any appreciable charge accumulation on said control electrode, the resistance of said coating being less than 20 megohms.

8. In an electron tube, an electron-emitting cathode, an anode, a control electrode of electrically conductive material interposed between said cathode and said anode and at least partially coated with a coating of resistance material, the resistance of said resistance material being at least a few hundred times that of said conductive material and low enough to prevent any appreciable charge accumulation on said control electrode, the resistance of said coating being less than 20 megohms.

9. In an electron tube, an electron-emitting cathode, an anode, and a control electrode of electrically conductive material interposed between said cathode and said anode and at least partially coated with a coating of resistance material, the resistance of said coating being high enough to reduce control electrode current to a small fraction of what it would be without said coating and low enough to prevent any appreciable charge accumulation on said control electrode, and said resistance being in the range between 0.05 and 20 megohms.

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