March 28, 1950 J. G. TRUMP ET AL 2,501,882

HIGH-VOLTAGE HIGH-VACUUM ACCELERATION TUBE

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Fig. 2.

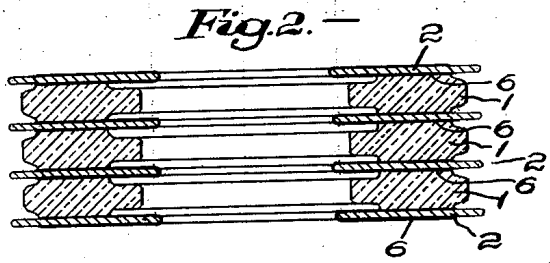


Fig. 3.

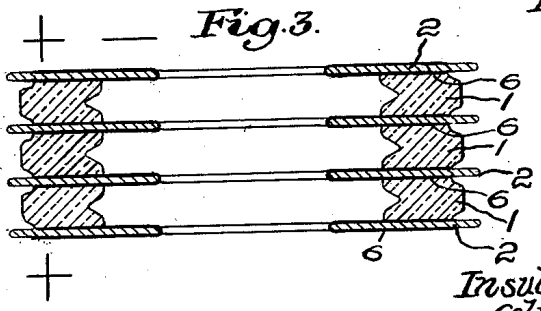


Fig. 4

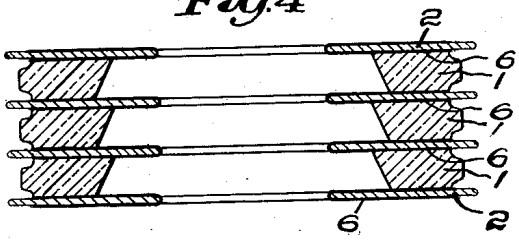


Fig. 5.

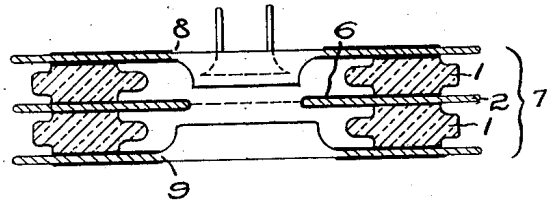
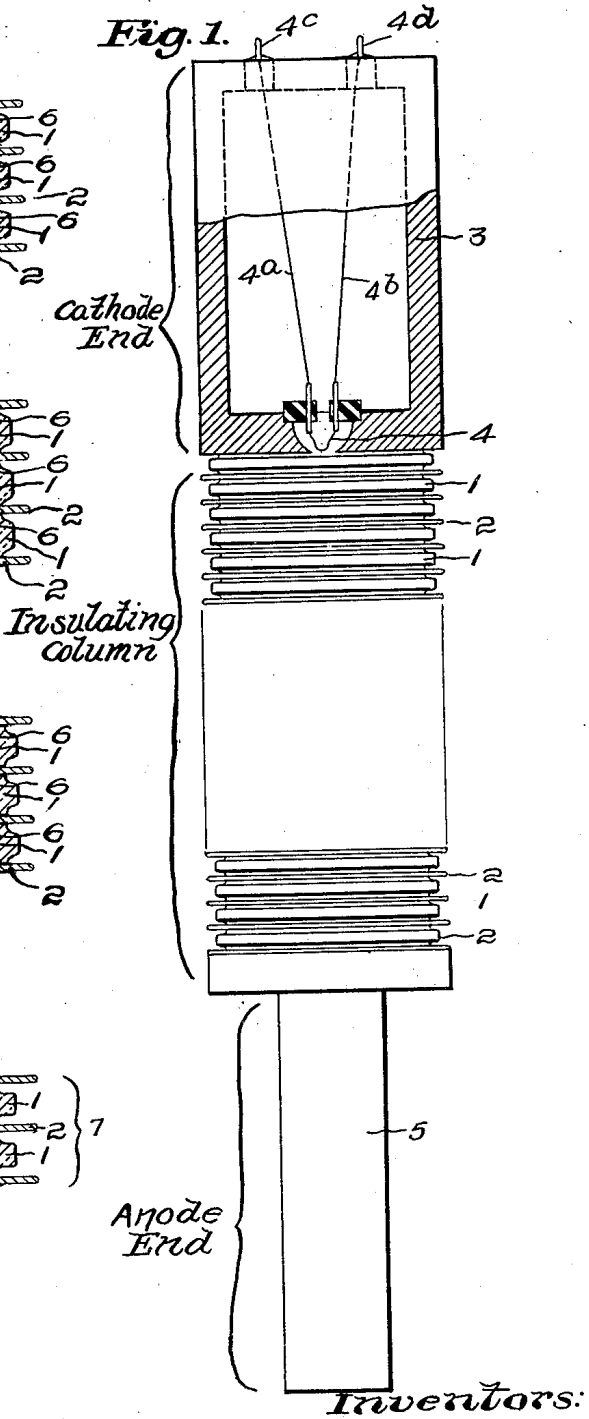


Fig. 1.



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HIGH-VOLTAGE HIGH-VACUUM ACCELERATION TUBE

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15 Claims. (Cl. 250—155)

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This invention particularly relates to high-voltage high-vacuum acceleration tubes of unusual voltage strength that provides a method of increasing the voltage insulating strength thereof between its electrodes and of reducing the emission of charged particles from the conducting surfaces of the electrodes in the tube column.

In order that the broad principle of the invention may be readily understood, we have in the accompanying drawing disclosed two embodiments or representations of apparatus indicative of such part of the invention, and by which the method of the invention may be practiced.

In the ensuing specification we shall describe such preferred embodiments of the novel acceleration tube but without limiting ourselves to such type of tube. We shall also herein set forth the best mode known to us for constructing the same.

In the drawing:

Fig. 1 is a side elevation, partly in transverse section at its upper or cathode end and partly broken away at an intermediate part of its length, of an evacuated electric discharge device or acceleration tube made up in this instance, in accordance with our invention, of a large number of alternating sections constituting metallic conducting electrodes having the shape of disks or rings, and of annular sections of insulating material, that portion of the conducting electrodes within the vacuum established in the tube being each covered with a thin insulating film;

Figs. 2, 3 and 4 are details in vertical transverse section, on a larger scale than in Fig. 1, of a portion of several of the conducting electrodes, each covered with a thin film of insulating material, excepting the edges thereof extending into the pressure regions, and of a portion of the intervening sections of insulating material, said sections of insulating material being shown of different contour in each of said figures; and

Fig. 5 is a vertical central cross-sectional view of a three-element electronic tube in which the conducting electrodes are covered with a thin film of insulating material.

High-voltage acceleration tubes for the acceleration of electrons and positive ions to high energies are required for the production of high-energy X-rays, cathode rays and positively charged particles used in nuclear research. Such acceleration tubes are commonly of a multiple acceleration type in which the charged particles undergo repeated acceleration while moving down the axis of an evacuated tube characterized by

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the employment of alternate annular rings of conducting and of insulating materials. Constant voltages are commonly impressed across the extreme terminals of such tubes, and this voltage is divided as uniformly as possible between the conducting electrodes or annular rings along the length of the tube by means of resistor or corona leakage.

Particularly for the production of X-rays in the energy range of several million volts and for the production of positive ions in this and in higher energy range, intensive efforts have heretofore been made to improve such acceleration tubes so as to accomplish the required acceleration along a tube column of reasonable length. For example, the air-insulated million-volt X-ray generator completed in 1937 for the Huntington Memorial Hospital, at Boston, Massachusetts, had an insulating column ten feet long and a gradient along its length of 100,000 volts per foot.

Both electron and positive-ion accelerators, particularly those employing electrostatic voltage sources are now commonly insulated in air, nitrogen, or some other gas at an elevated pressure, as set forth in our co-pending application Ser. No. 717,380, now Patent No. 2,460,201, January 25, 1949. Greater compactness is thereby made possible in the voltage-generating apparatus through the use of such superior insulating gaseous media.

Positive-ion accelerators have heretofore been built in which the column length of the electrostatic generator and also of the acceleration tube was four or five feet per million volts. In the relatively highly developed pressure-insulated electrostatic accelerators built by the Massachusetts Institute of Technology, at Cambridge, Massachusetts, during World War II, two million volts were insulated along a column fifty-four inches long. In such generator the limitation of the equipment occurred within the acceleration tube itself, and was due to insulation failure in vacuum at the higher voltages.

The last referred to accelerator represented the highest performance possible at that time, using the principle of multiple acceleration as disclosed in our said co-pending application (now Patent 2,460,201) and in other of our co-pending applications.

Further increases in the compactness of the generator and the accelerator tube columns (which are usually of equal length) were limited by the insulation strength within the evacuated tube.

Intensive efforts have been made by us to pro-

duce electrostatic accelerators in which still higher operating voltages and gradients could be realized along the generator and tube columns, and specifically for the purpose of attaining a two-million volt operating voltage along a column of twenty-four inches length. Such efforts also involved a study of the influence of the insulating material and of the electrode material and of the relative shapes of the electrode and the insulator.

In the course of such investigations and intensive efforts the mechanism of tube failure became better understood. An important contribution to the break-down and failure of acceleration tubes of the described compactness was found by us to arise because of the emission of charged particles from the metallic electrodes themselves, particularly from the region where the conducting and insulating members are in close proximity or are in contact.

An individual section of a multi-stage acceleration tube consists of an annular ring of insulating material, such as glass or porcelain, and a conducting or metallic diaphragm on each side of the ring of insulating material, with an axial orifice through which the beam of accelerated particles normally passes. Under the influence of high voltage and gradient the metallic electrodes of such a section of an acceleration tube become capable of emitting charged particles, and, if the voltage, gradient and other conditions are appropriate, may permit the passage of a complete or arc discharge which usually follows the contour of the insulator surface. The flash-over of an individual section of the acceleration tube results in the production of considerable ionization, due to the stored energy involved, and also causes the emission of gas from the metallic and insulator surfaces. This ionization (including the ions resulting from the gas) may be accelerated up the axis of the acceleration tube and thus be amplified by the total voltage of the acceleration tube. As a consequence, an initial and relatively minor discharge within an individual section of the acceleration tube may initiate an important discharge lengthwise the whole tube and thus reduce the permissible tube voltage.

In the course of our said investigations and when the foregoing physical picture had become clear to us, we made a study of the influence of insulating and other films placed on the electrode surface and of the proper relation of this film-covered electrode to the solid insulator abutting it at each surface. The film so applied by us was found to reduce very markedly the electronic emission from the electrode surfaces, and to delay the adverse effect which had led to tube failure.

As a result of the application by us of such film to the electrode surfaces of another acceleration tube of two-foot length, an operating voltage of two-million volts was insulated reliably, and no pre-sparkover currents were observed in bringing the tube up to such voltage for the first time.

Such accomplishment constitutes a performance dramatically different from the performance of acceleration tubes in which the electrodes thereof were not coated with an insulating film. Such latter tubes had to be brought up to voltage slowly, and the electrode surfaces had to be carefully outgassed by controlled sparkover and other devices, and yet they finally remained operative only at a lower voltage than can be obtained with the same elements, but with coated electrode surfaces in accordance with our herein disclosed invention.

We have in our said investigations culminating in the herein disclosed invention, found that the full results of this procedure are obtained if the film-covered surface is used in conjunction with an insulator whose vacuum-exposed surface has the proper contour and, in Figs. 2, 3 and 4 of the drawing, are shown insulator shapes which perform well with film-covered electrodes.

The film employed in accordance with our invention for covering the conducting electrodes, as herein disclosed, may be made of an insulating material such as glass, or it may be made of a synthetic resin such as polyvinyl acetate, or it may be made of other material that is characterized by low emission under high electric fields and electron or ion bombardment. Generally speaking, the use of insulating material to constitute the film gives superior results.

While we have particularly referred to multi-stage acceleration tubes, it is to be clearly understood that our herein disclosed invention is also useful in single-stage acceleration tubes, such as a conventional X-ray tube or rectifier, an example of which is shown in Fig. 5 of the drawing.

We have in the accompanying drawing shown the conducting electrodes each covered throughout (excepting their outer edges that extend into the compressed-gas portion of the system) with a thin insulating film, but our invention is not limited to covering entirely with a thin insulating film both faces and the inner vacuum-exposed edge of each electrode, though the best results are thereby obtained. The outer edge of each electrode extending into the pressure region need not be so covered, this being unnecessary. The portions of the surfaces of the electrodes extending into the vacuum must, in accordance with our invention, be covered in whole or in part with such film. We may, within the scope of our invention, cover only the cathode surface of each of the conducting electrodes with a thin film of insulating material. Within the scope and purpose of our invention, the portion of each of the metal electrodes that extends into the evacuated section of the tube and in close proximity to the insulators of the tube may, and for obtaining the best results should, be covered with a thin film of insulating material. That is, the portion of each electrode in contact or in close proximity to the solid insulators and the part within the evacuated portion of the tube may, and for best results should, be covered with a film of insulating material.

We have, in accordance with our invention, provided in a high-voltage high-vacuum acceleration tube, including a cathode, an anode and a column consisting of alternate annular sections of insulating and conducting materials, the conducting electrodes with the described thin insulating film, and particularly the portion of such electrodes extending into the evacuated section or portion of the acceleration tube in close proximity to the adjacent insulators.

Our invention comprehends an evacuated tube for the acceleration of charged particles to high energies, consisting of metallic electrodes at a high difference of potential, and solid insulating ring-like members separating such electrodes, the portion of each of the electrodes in contact or in close proximity to each solid insulator and the portion within the evacuated portion of the tube being covered with a film of insulating material, and most desirably the entire surface of the said electrodes being covered by the described film of insulating material excepting (as unnec-

essary to cover) the edge that extends into the compressed-gas portion of the system.

The method practiced by our invention, broadly stated, comprehends the increasing of the voltage insulating strength of an evacuated tube for the acceleration of charged particles between the electrodes thereof, and, more specifically stated, such method consists in coating at least a portion of each metallic electrode within the tube with a film of insulating material, and also in shaping the inner contour of each insulator of the tube column so as to impede the movement of charged particles along its surface.

Referring more particularly to the drawing, and first to Fig. 1, there is therein shown as a structure to which our invention is applied and by which the method practiced by our invention may be practiced, the assembly of a sealed-off two-million volt acceleration tube with the intermediate portion broken away, and the getter chamber at the cathode end partly in transverse section, which tube is in practice mounted within a high voltage generator in such way that the cathode end is within the high-voltage terminal and the tube column is within the column of the generator itself.

In said Fig. 1, the high-voltage vacuum tube is shown as consisting of a large number of alternating glass, porcelain or other insulation rings and a corresponding number of metallic electrode rings or ring-like diaphragms or disks.

In said Fig. 1, the glass or other insulation rings are respectively indicated at 1, and the metal electrode rings, centrally-open diaphragms or disks are indicated at 2. The said metal rings, diaphragms or disks 2 lie accurately placed in planes perpendicular to the axis of the acceleration tube and are placed at equal distances apart, as, for example, one-third of an inch.

As merely typical of an acceleration tube embodying our invention, or to which our invention is applied, but to which it is not restricted, it may be stated that the over-all length of the acceleration tube shown is about four feet and the inside diameter thereof is about three inches. The diameter of the opening of each metal ring 2 is about two inches, the total length of that portion of the acceleration tube composed of the insulation rings 1 and the metal rings 2 being in the present example about twenty-four inches.

Within the upper or cathode end 3 of the acceleration tube above or in the horizontal plane of the uppermost metallic ring 2 is positioned the hair-pin filament or electron emitter 4 from which emanates the electron beam, and which emitter 4 may be composed of tungsten, it being connected by suitable circuit wiring 4*a*, 4*b* with the electrode leads 4*c*, 4*d*. The cathode assembly, diagrammatically shown at 3, also contains the charcoal and getter material for the absorption of residual gases. Where the apparatus is used for generating X-rays, as for high voltage radiography, the electron beam is focused on a target preferably of gold at the lower or anode end 5 of the tube.

In each of Figs. 2, 3 and 4 is represented in vertical cross-section and upon a larger scale than in Fig. 1, only a small portion of the insulating column of the acceleration tube. Each of said figures shows merely four of the metallic electrode rings 2 and three of the glass or porcelin insulating rings 1, because of space limitations of the sheet of drawings.

The said insulation rings 1 are carefully contoured at both their inner and their outer edges and particularly at their inner edges. In each of said Figs. 2, 3 and 4 are shown insulation rings 1, the inner edges whereof (shaped as shown) perform well with film-covered metallic electrodes in accordance with our invention. Each of the shapes shown respectively in Figs. 2, 3 and 4 serves to impede the movement of charged particles along the inner surface of the insulators 1. Our invention, however, is not limited to the three shapes of insulation rings shown.

In accordance with our invention, substantially the entire surface of each of the metallic electrodes (a few only of which are shown in Figs. 2, 3 and 4), i. e. both the upper and the lower faces and the inner edge thereof, but not necessarily the outer edge, are covered with a thin film 6 of synthetic resin such as polyvinyl acetate, or it may be other material, such as glass, porcelain enamel or a metal oxide, that is characterized by low emission under high electric fields and electron or ion bombardment. Merely as an example of a polyvinyl acetate that may be used for the purpose, but to which our invention is not limited, we mention Vinylseal T–24–9 made by the Union Carbide & Carbon Company.

Fig. 5 shows in vertical, central, cross-section a three-element electronic tube indicated generally at 7, in which are shown two insulator rings 1 and a single metallic electrode 2, together constituting the column. The entire surface of the said electrode 2, except the outer edge, and a considerable portion of the cathode and anode electrodes 8 and 9 are covered with a thin film 6 of insulating material such as described with reference to Figs. 2, 3 and 4. With respect to the cathode and anode electrodes 8, 9, it is helpful to apply the film 6 to such portions thereof as are subjected to a high electric field, though not directly involved either with the emission of electrons (as is the filament, for example) or with the receipt of the electrons (as is that portion of the anode upon which the electrons impinge).

We preferably coat with the thin film at least the cathode surface of each of the metallic electrodes, that is, the upper surface thereof in each of Figs. 1, 2, 3 and 4, and we desirably coat with the film at least that part of the surface of each metallic electrode that is within the evacuated portion of the tube.

As stated, the full results of the invention are obtained if the metallic electrodes having their surfaces substantially covered with a thin film of insulating material (except the outer edge) are used in conjunction with ring-like insulator sections whose vacuum-exposed surfaces have the proper contour, examples of the proper contouring being shown in Figs. 2, 3 and 4.

It will be understood that the herein disclosed method increases the insulating strength of the evacuated tube.

Having thus particularly described two embodiments of the apparatus of our invention and having disclosed the method practiced thereby, it is to be understood that although specific terms are employed, they are used in a generic and descriptive sense and not for purposes of limitation, the scope of the invention being set forth in the following claims.

We claim:

1. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode and a column consisting of alternate annular sections of insulating material and conducting material consti-

tuting electrodes, the said conducting electrodes each having applied to the surface thereof merely a thin insulating film, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

2. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode, and a column consisting of alternate annular sections of insulating material and of conducting material constituting electrodes, the said conducting electrodes being each substantially covered with merely a thin insulating film, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

3. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode, and a column consisting of alternate annular sections of insulating material and of conducting material constituting electrodes, at least the cathode surface of each of said conducting electrodes being covered with merely a thin film of insulating material, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

4. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode, and a column consisting of alternate annular sections of insulating material and of conducting material constituting electrodes, each of said conducting electrodes including said cathode and said anode being metallic and each being substantially covered with an insulating film, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

5. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode, and a column consisting of alternate annular sections of insulating material and of conducting material constituting electrodes, each of said conducting electrodes being metallic and having a portion extending into the evacuated portion of the tube, such portions of the said metallic electrodes extending into the evacuated section of the tube being covered with merely a thin film of insulating material in close proximity to the said sections of insulating material, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

6. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode, and a column consisting of alternate annular sections of insulating material and of conducting material constituting electrodes, each of said conducting electrodes having at least a portion of its surface covered with merely a thin film of insulating material to increase the insulating strength of the tube, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

7. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode and a column consisting of alternating annular sections of insulating material and conducting material constituting electrodes, the said conducting electrodes each having applied to the surface thereof merely a thin insulating film, the said film being composed of glass, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

8. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode, and a column consisting of alternate annular sections of insulating material and conducting material constituting electrodes, the said conducting electrodes each having applied to the surface thereof merely a thin insulating film, the said film being composed of a synthetic resin, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

9. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode and a column consisting of alternate annular sections of insulating material and conducting material constituting electrodes, the said conducting electrodes each having applied to the surface thereof merely a thin insulating film, the said film being composed of material characterized by low emission under high electric fields and electron or ion bombardment, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

10. A three-element high-voltage electronic tube having applied to the surfaces of the conducting electrodes merely a film of insulating material, for the purpose of and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage tubes, said films upon said electrodes being incapable of

supporting the total voltage between the said electrodes.

11. A three-element high-voltage electronic tube having the surfaces of the conducting electrodes substantially covered with merely a thin film of insulating material, for the purpose of and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

12. A high-voltage, high-vacuum, acceleration tube comprising a cathode, an anode and a column consisting of alternate annular sections of insulating material and conducting material constituting electrodes, the said conducing electrodes each having applied to the surface thereof of a merely thin insulating film, the said cathode and the said anode having such thin insulating film applied to the surfaces thereof not directly involved with the emission or with the receipt of the electrons, but which are subjected to a high electric field, for the purpose of reducing and acting, when applied to the said electrodes, to reduce the emission of electrons and positive ions from the said electrodes when bombarded by high energy particles such as are always present in high-voltage acceleration tubes, said films upon said electrodes being incapable of supporting the total voltage between the said electrodes.

13. A three-element electronic tube having merely a film of insulating material applied to all the three metallic electrode elements thereof, excepting those actual cathode areas which are intended for the emission of electrons and those actual anode areas upon which the electrons impinge, the said film of insulating material, when applied to the electrode elements, being for the purpose of reducing the emission of electrons and positive ions from the said metallic electrodes when bombarded by high energy particles.

14. A high-voltage high-vacuum acceleration tube comprising a multiplicity of annulear metallic electrodes and a corresponding multiplicity of insulating annular members alternating throughout with said metallic electrodes, a cathode at one end of said tube and an anode at the opposite end thereof, whereby, in the operation of said acceleration tube, a column of swift particles passes from the cathode to the anode through the openings of the said annular electrodes and annular insulating members, the exposed surfaces of substantially all the said electrodes being coated with a merely thin film of insulating material for the purpose of increasing the voltage insulating strength between the said electrodes and of reducing the emission of charged particles from the conducting surfaces of the said electrodes in the operation of the said acceleration tube.

15. A high-voltage high-vacuum, electron and positive-ion, acceleration tube comprising a multiplicity of annular metallic electrodes and a corresponding multiplicity of insulating annular members alternating throughout with said metallic electrodes, a cathode at one end of said tube and an anode at the opposite end thereof, the capability of the surfaces of said metallic electrodes themselves to emit electrons, when under the bombardment of a column of high-energy swift particles that are emitted from said cathode, being markedly reduced by a merely thin coating film of insulating material characterized by low emission under high electric fields and electron or ion bombardment, the said thin coating film being applied to and covering at least the cathode surface of substantially each of the said metallic electrodes, and thereby also increasing the voltage insulating strength between the said electrodes.

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