United States Patent

[11] **3,588,565**

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[54] **LOW DOSE RATE HIGH OUTPUT ELECTRON BEAM TUBE**
10 Claims, 11 Drawing Figs.

[52] **U.S. Cl.** **313/74,** 250/49.5, 313/189, 315/334
[51] **Int. Cl.** **H01j 33/00**
[50] **Field of Search** 313/74, 189; 250/49.5 (0), 49.5 (7); 204/157.1

[56] **References Cited**

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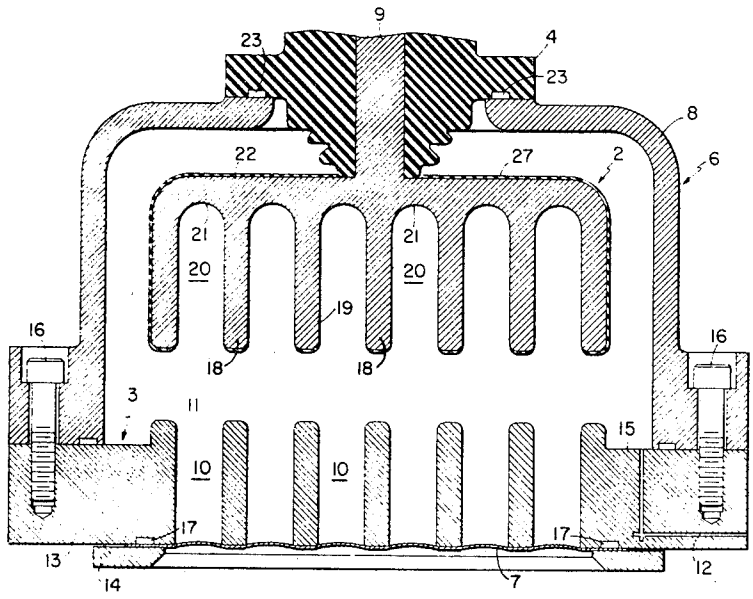
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Primary Examiner—Raymond F. Hossfeld
Attorneys—Henry C. Nields and Francis J. Thornton

ABSTRACT: Electrons having energy of the order of hundreds of kilovolts are produced over a wide area by a vacuum tight tube containing gas at low pressure which becomes ionized. Electrons are released at the cathode surface in hollow depressions in that surface extending over a large area by secondary emission caused by bombardment of the cathode surface with positive ions and by collision ionization processes in the gas. The electrons thus released are accelerated and focused into apertures in the anode which are covered with thin electron windows through which the electrons issue as uniform and parallel streams suitable for the simultaneous irradiation of coatings and like materials over a large area.



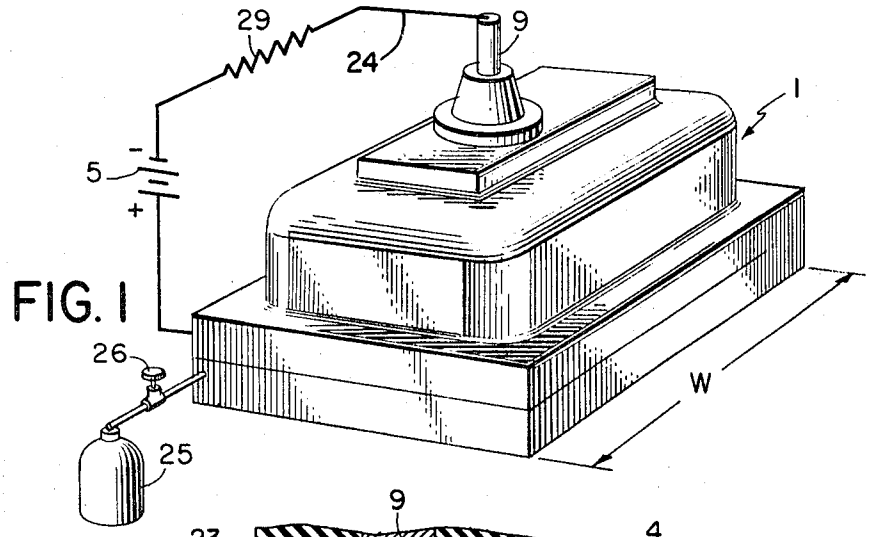


FIG. 1

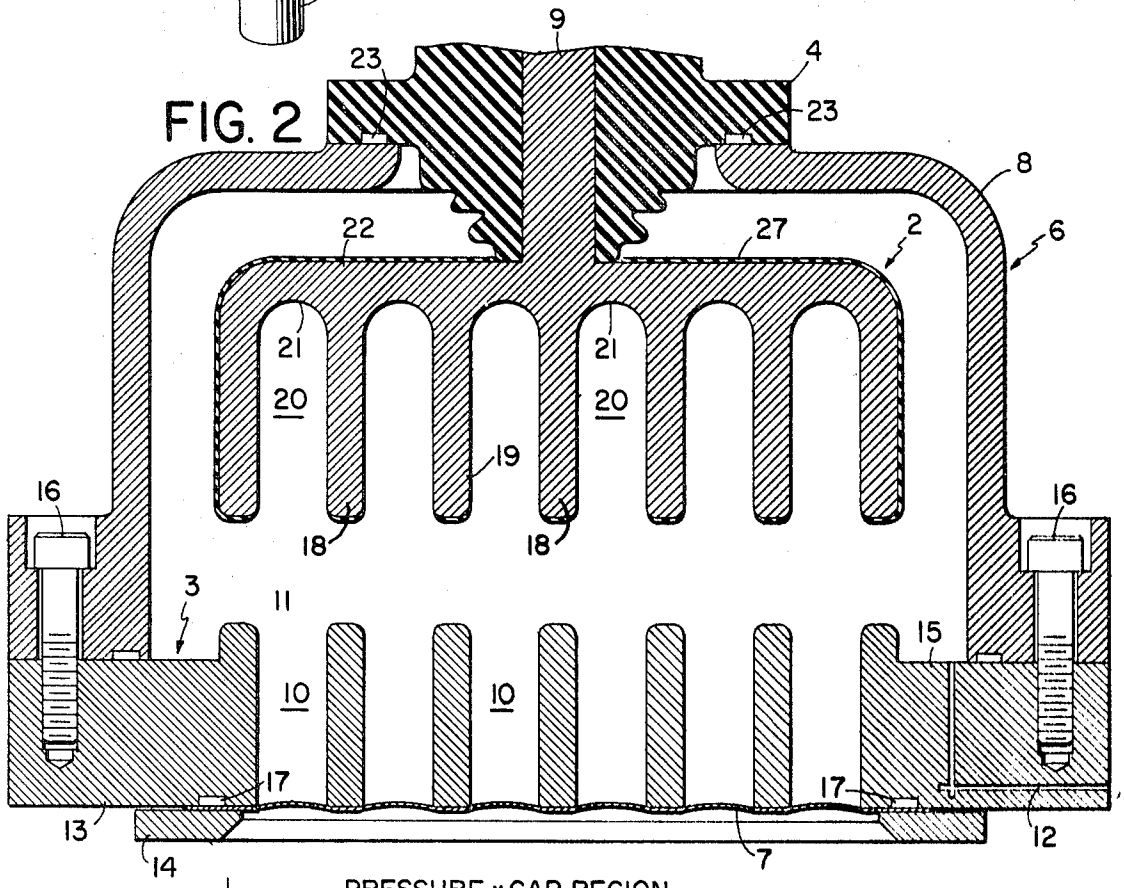


FIG. 2

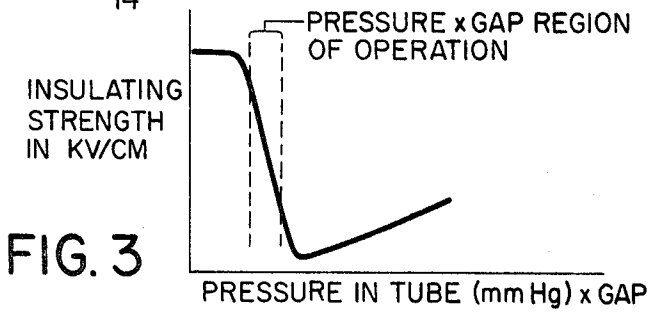


FIG. 3

FIG. 4

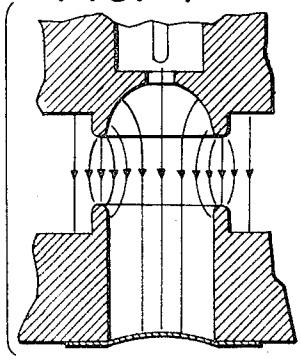


FIG. 5

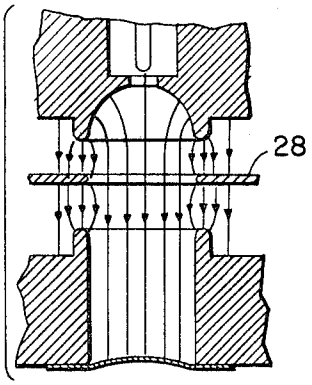
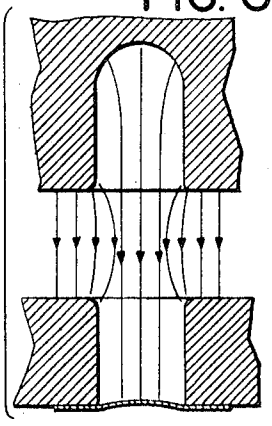


FIG. 6



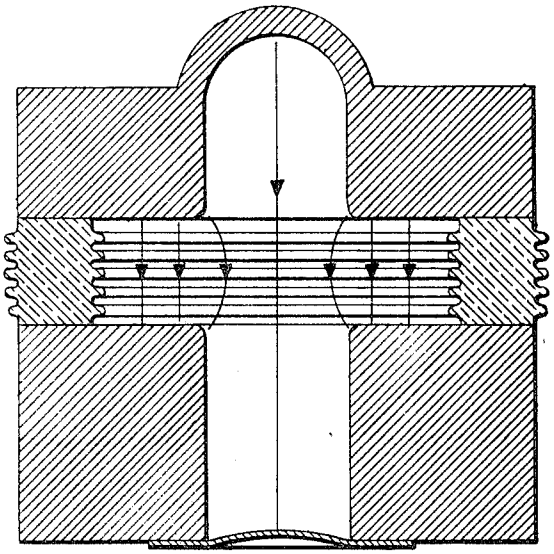


FIG. 7

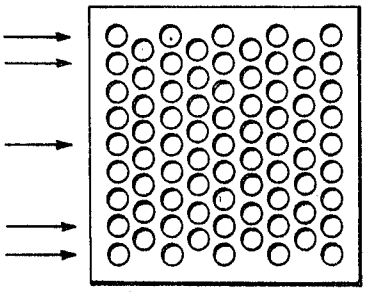


FIG. 8

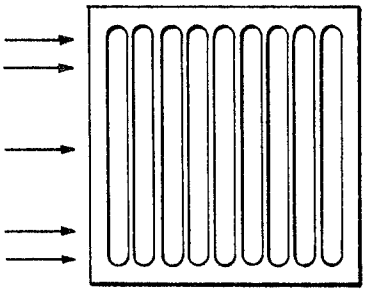


FIG. 9

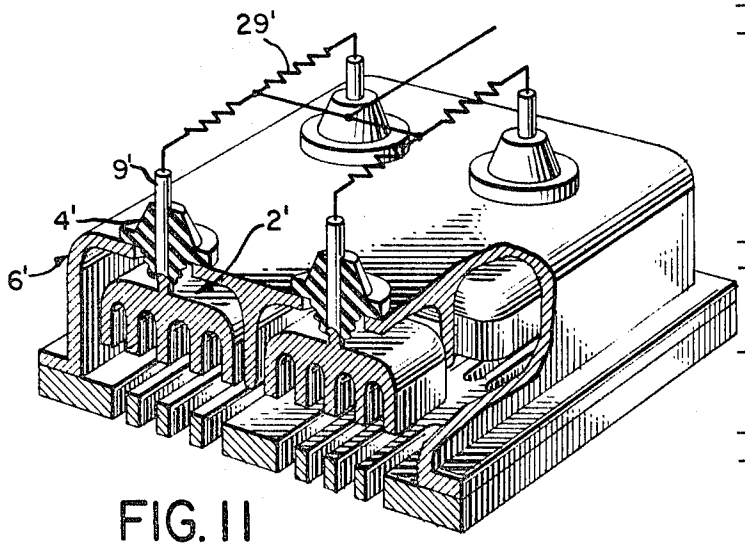


FIG. 11

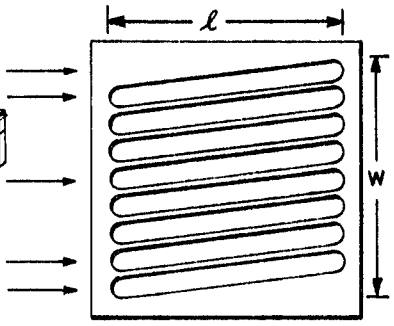


FIG. 10

LOW DOSE RATE HIGH OUTPUT ELECTRON BEAM TUBE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to the curing of coatings, and in particular to the curing of coatings by means of ionizing radiation in the form of electrons.

2. Description of the Prior Art

The curing of coatings by means of irradiation with electrons has followed the techniques used in the electron irradiation of other materials. Such techniques have almost universally employed an evacuated acceleration tube in which electrons are accelerated to high energy as a well-focused pencil-like beam. The beam emerges from the vacuum region of the acceleration tube into the atmosphere through a so-called electron window comprising a thin foil of some low-atomic-number material, such as beryllium or aluminum, and the accelerated beam is spread out in at least one dimension by some appropriate means, such as scanning or divergent focusing. See, for example, U.S. Pat. No. 3,330,748 issued July 11, 1967 to E. J. Lawton and entitled "Method and Apparatus for Irradiating Organic Polymers with Electrons;" British Pat. Specification No. 828,717 published Feb. 24, 1960 and entitled "Improved relating to the Curing of Plastics;" British Pat. Specification No. 907,688 published Oct. 10, 1962 and entitled "Improvements in or relating to the Production of Cured Coatings of Polymeric Material;" and British Pat. Specification No. 991,561 published May 12, 1965 and entitled "Improvements in Coatings of Compositions Comprising a Polyester." Problems associated with these techniques include relatively high dose rate and relatively low output. Reasonably uniform dose over the material irradiated is difficult to achieve with thermionic-emission cathodes of large area, and so filamentary cathodes are employed which produce a pencil-like beam of inherently limited current. Not only is output thus limited, but dose rate is relatively high in such a beam even when it is scanned.

SUMMARY

The invention comprehends the production of streams of electrons suitable for the irradiation of coatings. Among the advantages of the invention are the relatively large cross section of the electron streams with correspondingly large output, and the relatively low dose rate achieved by spreading the electron current simultaneously over a large area. All this is achieved without sacrificing uniformity of dose over the area irradiated. To accomplish these and other objectives the invention employs a very large area cathode from which electrons are caused to be emitted by bombardment with positive ions. The source of the bombarding ions is a gas which is deliberately introduced into the acceleration tube; in other words, the tube is not evacuated in the manner of the prior art. In this way, the ion bombardment, and hence the electron emission, occurs over a very wide area. The invention includes, not only the emission of electrons over a wide area, but also the precise acceleration of these electrons by a carefully defined electric field distribution to focus multiple parallel streams of electrons to arrive at the electron permeable areas only of the anode.

Thus the objective of the invention is to produce a large quantity of electron ionizing power uniformly over a large area for the purpose of irradiating a thin industrial coating at a low dose rate but with a high throughput of product.

The low dose rate takes advantage of the fact pointed out for the past 10 years that some radiation reactions proceed more efficiently at low dose rate. Another advantage of low dose rate is that it offers the opportunity of greatly increasing the window area and the resultant power loss per unit area in the window can eliminate the need of flowing on the window for cooling purposes. Never a really easy thing to do, blowing is particularly disadvantageous when the coating involves dry powders and particles.

An important part of the proposed acceleration tube is the multiple-opening window construction.

The invention includes, not only the emission of electrons over a wide area, but also the precise acceleration of these electrons by a carefully defined electric field distribution in order to focus multiple parallel streams of electrons to and through the multiple windows with virtually no electrons wasted by bombarding parts of the anode structure.

Thus wide and uniform area irradiation is achieved without scanning.

The high electron output is the result of multiplying a low current electron beam by a large number of individual focused beams in parallel or by a large number of inches of extended line beam. If the electron current per individual window opening (or per inch of "line" opening) is low enough, it will be possible to dispense with forced gas cooling. This sub-gas-blowing level is at about 200 microamperes per individual opening and 400 microamperes per inch of line opening.

A feature of the system is that it is very modular; the performance of one beam element can be studied and developed and thereafter the multiple beam system can be predicted.

The method of the invention includes the step of adjusting the pressure of the residual gas to the proper level. The pressure depends on the anode-to-cathode distance, on the shape and material of the cathode, on the nature of the residual gas, and on the desired voltage and current density. In general the proper pressure will lie between 5×10^{-4} mm. Hg. and 5×10^{-2} mm. Hg. For highest voltage operation the pressure may need to be as low as 1×10^{-4} mm. Hg.

The method of invention makes use of a principle which was commonly used at the end of the 19th century: namely, the production of an electron stream by bombardment of a cathode by positive ions produced in the cathode-to-anode space by electron collisions with residual gas atoms. This principle was involved in the tube used by Roentgen when he discovered x-rays in 1895. These gas-filled high voltage tubes began to disappear with the development of the tungsten filament by W. D. Coolidge and others about 1913. In recent years high energy electron streams have been produced exclusively from electrons emitted thermionically, with the exception of the pulsed avalanche discharge utilized in the Capacitron of Brasch and his associates.

In accordance with the foregoing principle, the returning positive ions bombard the cathode and release electrons by the process known as secondary electron emission. About 2 to 20 or more electrons per positive ion can be expected, depending on the energy of the ion, the nature of the cathode, the angle of incidence of the ion, and finally, to a relatively small extent, the nature of the ion.

In the simpler case of a uniform field, gaseous discharge at current levels where space charge effects can be neglected, the positive ion current is given by

$$I_+=I_o\epsilon^{\alpha d}$$

where I_+ is the positive ion current arriving at the cathode, I_o is the electron current leaving the cathode, α is the Townsend alpha coefficient for ionization of the gas at that condition of pressure and gradient, and d is the path length between cathode and anode.

BRIEF DESCRIPTION OF THE DRAWING

The invention may best be understood from the following detailed description thereof, having reference to the accompanying drawings, in which:

FIG. 1 is a view in perspective of an acceleration tube embodying the principles of the invention;

FIG. 2 is a vertical section of the acceleration tube of FIG. 1;

FIG. 3 is a graph showing insulating strength, across a fixed gap, of a gaseous medium as a function of gas pressure;

FIG. 4 is a view similar to that of FIG. 2 and showing the fringing focusing field system of the invention;

FIG. 5 is a view similar to that of FIG. 4 and showing an alternate field system;

FIG. 6 is a view similar to that of FIG. 4 and showing another alternate field system;

FIG. 7 is a view similar to that of FIG. 2 and showing a single line beam tube;

FIG. 8 is a horizontal section taken through the anode of the acceleration tube of FIG. 2;

FIG. 9 is a view similar to that of FIG. 8 and showing a modification thereof;

FIG. 10 is a view similar to that of FIG. 8 and showing another modification thereof; and

FIG. 11 is a view in perspective of an acceleration tube embodying the principles of the invention and having a modified form of cathode.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, therein is shown an acceleration tube 1 comprising in essence a cathode 2 and an anode 3 separated by an insulator 4. A voltage is applied between the cathode and the anode by means of a suitable voltage source 5. The voltage thus applied is preferably in the 100 kilovolt range: that is to say, just enough to get through the thin metal window 7 hereinafter described and a few inches of intervening air and a few mils of coating. An output electron energy of 50 Kev. leaving the window would be adequate for most thin flat surfaces.

The acceleration tube 1, as a system for producing a large output of directed electrons with electron energies (after emerging from the metal window) generally in the range of 25 Kev. to 100 Kev., and preferably 50 Kev., for irradiating over a large area with uniform distribution of electron power over that area, will require the following elements:

a. a vacuumtight enclosure, as shown at 6,
b. a source of negative high voltage power, as shown at 5,
c. a cathode electrode connected to (b) on which are distributed a plurality of electron-emitting sources, as hereinafter described,
d. in special cases, as for higher output voltages or for special current control, one or more intermediate electrodes at a potential positive with respect to (c) when used for higher output energy, or controllable with respect to (c) when used to grid-control the cathode current, as hereinafter described,
e. an anode electrode which may be at earth potential, as shown at 3,
f. a rigid metallic structure at earth potential containing a distribution of holes or slots conforming to the pattern of the electron-emitting sources in (c), as hereinafter described, ((e) and (f) can be combined),
g. an electron-permeable metallic membrane covering the holes or slots in (f) so as to complete the vacuumtight enclosure, as hereinafter described.

In the above, (c), (d), (e), and (f) are so related geometrically and electrically that substantially all the accelerated electrons are incident upon the metallic membrane (g). The electron-emitting, accelerating, and electron-permeable system are each distributed over such an extended area that currents in excess of 10 milliamperes can be transmitted through the membrane (g) without the assistance of the forced-air cooling thereof. The electron-permeable but vacuumtight membrane may be a single metallic sheet covering the entire system of apertures in (f). The rigid member (f) supporting the metallic membrane (g) may have separations between holes or slots of considerable dimensions without reducing the efficient transmission of the accelerated electrons from cathode (c) to membrane (g).

The hermetically sealed enclosure 6 is formed by an electron-permeable window 7, the anode 3, a metallic sidewall 8, the insulator or the bushing 4, and the cathode support 9. The mechanical support for the enclosure 6 is provided by the anode 3, the sidewall 8, and the bushing 4. The anode 3 and the sidewall 8 are at ground potential, and a negative potential is applied via the cathode support 9 to the cathode 2, insulation being supplied by the bushing 4.

The anode 3 is relatively thick and is perforated by apertures 10 which may be elongated along the longest dimension (i.e. the width w) of the anode 3. The depth of these apertures 10 may be augmented somewhat and the focusing action augmented through the provision of the ridges 11 along their edges, so that the depth of the apertures 10 is greater than the thickness of the anode 3, although the provision of such ridges 11 is not essential. A conduit 12 may be provided in the anode 3 for entrance and exit of gas. The outer surface 13 of the anode 3 is preferably not provided with ridges, but is flat, and a single sheet of electron-permeable material 7 is laid over the outer surface 13 of the anode 3 and affixed thereto by means of a retaining member 14 which is bolted to the anode 3. The sidewall 8 is bolted to the upper surface 15 of the anode by bolts 16, and vacuum seals 17 are provided between the sidewall 8 and the anode 3 and also between the anode 3 and the electron-permeable window 7.

The cathode 2 may have ridges 18 corresponding to those of the anode 3, which are formed on the inner surface 19 of the cathode 2 so that the hollows 20 between the ridges 18 terminate in well-rounded surfaces 21. However, such ridges may be omitted, and in that event the edges of the hollows 20 may simply be rounded, bolted or otherwise affixed to the cathode support 9, or indeed may be formed integrally therewith. Vacuum seals 23 should be provided between the bushing 4 and the sidewall 8 and between the bushing 4 and the cathode support 9.

A voltage of several hundred kilovolts negative is generated by the voltage source 5 and applied to the cathode support 9 via a suitable lead or cable 24.

A gas supply 25 is connected to the conduit 12 via a valve 26, so that the amount of gas pressure in the hermetically sealed enclosure 6 may be regulated. If the gas is H_2, the valve 26 may comprise an electrically operated palladium valve.

The structure of the hollows 10, 20 in the inner surfaces of the anode 3 and cathode 2 are such that all potential ionizing paths within the tube 1 are short relative to the distance between the rounded cathode emission surface 21 and the thin electron window 7, and the gas pressure is adjusted so that ionization takes place predominantly (i.e. almost entirely) along the longer path. Thus the production and acceleration of electrons is confined primarily to those regions where the accelerated electrons may issue from the tube 1 through the electron window 7.

Unwanted electron emission may be further repressed by coating areas of the cathode other than the reentrant cathode surface with a dielectric coating 27 comprising glass, porcelain, or epoxy, which coating is thin with respect to the minimum cathode-anode spacing.

The presence of the hollows 10, 20 also serves to shape the electric field in such a way as to provide a focusing effect on the accelerated electrons so as to ensure that the accelerated electrons pass out through the window 7 and are not lost as wasted power by striking the walls of the tube 1.

An important feature of the invention is the use of a deep hollow cathode to enhance the electron beam current arising from secondary emission and gaseous ionization processes. The choice of cathode metal also has an influence. Aluminum has often been used but more emissive metals are now known. The cathode plate and indeed also the anode window-support plate, can be cut in one piece. The virtues of the hollow cathode in encouraging the release of free electrons for beam-forming purposes are probably related to the longer ionization path in gas, plus electron and ion scattering and thus bombardment at other angles including glancing incidence, plus possibly also photoemission from the surrounding internal walls of the hollow cathode.

The pressure of the residual gas should be maintained at a level (between 5×10^{14} and 5×10^{12} mm. Hg. in the vicinity of a 10 cm. gap) adequate to produce the required electron cur-

rent, as by some simple means of modifying the pressure. For example, the gas supply **25** may include a pump and a gas control such as the valve **26** may be provided for maintaining the desired residual pressure. An ionization gauge may be used to sense the gas pressure and to regulate the pressure to the desired operating level. The relationship between gas pressure and insulating strength is shown in the graph of FIG. **3**. The graph of FIG. **3** illustrates Paschen's Law, which states that for parallel plane electrodes in a particular gas at a particular temperature the breakdown voltage is a function only of the product of the pressure and the electrode separation. The typical form of the function is well known in the art and is set forth in the graph of FIG. **3**. The graph exhibits a minimum breakdown voltage which is usually referred to as the Paschen minimum. It is clear from an inspection of the graph of FIG. **3** that for a given tube configuration and for a given pressure in that tube, if the maximum possible gap length in the tube between the cathode and anode thereof is such that the product of pressure times gap length is below the Paschen minimum, then as the pressure is raised from very low values, breakdown will occur across those portions of the anode and cathode which are more remote from one another rather than from those portions of cathode and anode which are closer to one another. In other words, if the configuration of anode and cathode is such that the spacing therebetween is not uniform, but at certain portions of the tube the spacing between cathode and anode is greater than the spacing at other portions of the tube, it then follows that breakdown will first occur between the more remotely spaced portions and, provided that the pressure within the tube is not increased above the pressure at which such breakdown occurs, breakdown will be limited to those portions of the tube and will not occur between the more closely spaced portions of anode and cathode as long as the pressure remains at the value mentioned. The gas pressure must be held at that balance between excessive gas conductivity and excessive insulation strength with too little conductivity. This can be done by (a) measuring the pressure; (b) being prepared to introduce more gas as the tube cleans up; and (c) combining (a) and (b) automatically.

In order to stabilize the voltage/current relationship, a current-stabilizing element may be introduced in series between the power supply **5** and the discharge tube **1**. Such current-stabilizing element may comprise a resistor **29**, as shown in FIG. **1**, or an electronic stabilization device, or any other suitable element.

The gas pressure will in general gradually reduce due to "ion pumping." This phenomenon is commonly referred to as "gas clean-up." In the old days, a vacuum tube would be rejuvenated by adding some gas, usually by heating a small side tube containing some carbonaceous or calciumlike material. In accordance with the invention it may be preferable to use a noble gas like helium or argon as these do not ion pump readily. However, the gas may also be a vapor, such as the vapor of Hg. for example. The gas ought to be one that does not attack the metal. A vapor may be temperature sensitive, which is a disadvantage.

The management of the electric fields is one of the important features of the proposed tubes. The tube has many parallel electron beams which are intended to be identical in their current-voltage characteristics and which therefore deliver an effectively uniform distribution of energetic electrons through the multiply-apertured window.

An important feature of the system is that each electron beam is independent of the others.

Another feature of the system is that each beam is well focused so that very nearly all the accelerated electrons reach the exit window thereby reducing the power loss, the heating of the anode, the unwanted x-ray background. This focusing is accomplished by the fringing focusing field system illustrated in FIGS. **4**, **5**, and **6**. There may be one or more intermediate electrodes supported between the cathode electrode and the anode electrode at a potential (preferably controllable) positive with respect to the cathode electrode, or none. One such intermediate electrode is shown at **28** in FIG. **5**. Intermediate electrodes would begin to be useful at total applied voltages of 200 kilovolts or more.

Maximum interelectrode path length should be along the central axis between the rounded cathode emission surface **21** and the anode apertures **10**, where the electron beam current is desired.

The multiple line beam tube with cold cathodes shown in FIGS. **1** and **2** may be a yard or more wide. The invention also comprehends single line beam tubes, as shown in FIG. **7**. The voltage and current ranges are determined by the geometry and gas pressure.

The hollow cathode—gap—hollow anode construction also has ideal beam focusing properties. The electrons and ions will be drawn by the inward fringing electric field into a fairly well axially focused beam. Very few electrons will not reach the electron permeable metal window. It is important that the longest path in the direction of the field exists between cathode and anode. Preferably the cathode-anode distance in which the positive ions are produced is several times longer than any other cathode-anode distances where no electron beam currents are desired.

Some possible patterns for the anode apertures are shown in FIGS. **8**, **9** and **10**. The pattern shown in FIG. **8** comprises rows of holes, spaced from each other insure rigidity of the anode and recognition that the electron beams will blend into uniform irradiation of the large "work" area because of the scattering by the window and the air intervening between the window and the "work" to be irradiated. The rows of holes are preferably staggered, as shown. The "work" to be irradiated flows in the direction of the arrow.

The pattern shown in FIG. **9** comprises rows of slots transverse to the direction of product movement.

The pattern shown in FIG. **10** comprises rows of slots nearly parallel to the direction of product movement. This arrangement makes for a more rigid anode if the length *e* along the direction of product movement is shorter than the width *w* transverse to the direction of product movement.

The pattern of an area filled with identical holes as shown in FIG. **8** has advantages in (1) mechanical strength, (2) modular construction and original development, (3) improved window cooling, (4) possibly easier fabrication, and (5) possibly better "hollow cathode" operation.

The cathode **2** need not be formed from a single block, and particularly for very large areas it may be desirable to subdivide the cathode **2** into any number of units up to the number of hollows **20**.

A representative arrangement of this sort is shown in FIG. **11**, wherein four units **2'** are shown. In the event that the cathode is thus subdivided, it will be convenient to provide with its own resistor **29'**. Although in FIG. **11** each unit **2'** is shown as having its own cathode support **9'** and its own bushing **4'**, so that the resistors **29'** are located outside the enclosure **6'** the resistors or other current-stabilizing device may also be positioned within the enclosure **6'** without departing from the spirit and scope of the invention.

The secondary electron emission mechanism of supplying the electron current would have a number of advantages for a 'low dose rate' high output power tube for the irradiation of thin industrial coatings. Among these are:

1. The electron current density will naturally be more uniform over the large emission (window) area we are planning for these tubes. This is because the current per element is dependent on gap pressure (which must be uniform in the same enclosure), on the geometry (which can easily be made accurately the same for each of the elements or focused modules), on the voltage (which is identical for each module), and on the material of cathode and gas (which is also identical).
2. This gas discharge method is suitable for low current densities of about 0.1 to 1 milliamperes per square inch of window area. It can go higher or lower but this range is comfortable and is close to what the coating requirement calls for.

3. The secondary emission process if particularly suitable to the 100 Kev. to 200 Kev. energy range needed for thin industrial coatings. In this voltage range only one acceleration gap is needed; this would eliminate the intermediate acceleration electrodes.
4. The secondary emission cathode eliminates all of three main disadvantages of hot emission: the danger of filament burnout, the large amount of heater power especially with extended filaments, the nonuniformity of current distribution due to the IR drop bias along a long filament. The secondary emission hardware is of course also considerably simpler.

In the voltage-pressure region of operation of the invention the current and voltage will be dependent on each other. At a given operating pressure the beam current will increase with voltage. It will therefore be feasible to adjust the current by modifying the voltage especially since the dose-rate does not have a primary dependence on voltage. On the other hand, it may be difficult to get enough current at the lowest end of the pressure range where the insulation strength becomes very high. Here the 'hollow cathode' feature should help.

It should not be implied that the beam electrons come only from the bombardment of the cathode metal by the returning positive ions and from electron ionization of the gas by the Townsend alpha collision process. The positive ions may also produce electrons by ionization of the gas as they travel toward the cathode. This is the well-known Townsend β process which he suggested in 1903 and which was later shown by others to be of little quantitative effect until the positive ions had attained sufficient velocity, comparable in fact to the velocity required of electrons for ionizing capability. But in the high voltage gas discharge tube of the invention the positive ions do indeed acquire the requisite energy (and velocity) to produce significant amounts of electrons by ionization of the gas.

Thus electrons travelling toward the anode and window are made up of:

a. secondary electrons from positive ion bombardment of cathode;
b. electrons by ionization of gas by accelerated electrons;
c. electrons photoemitted from cathode;
d. electrons by ionization of gas by positive ions.

The positive ions travelling toward the cathode are produced by:

a. ionization of the gas by the accelerated electrons;
b. ionization of the gas by the accelerated positive ions.

Having thus described the principles of the invention together with several illustrative embodiments thereof, 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.

I claim:

1. A method of irradiating coatings and other thin materials with energetic electrons, which method comprises enclosing a gas between a cathode having at least one electron-emissive area and an anode, having at least one electron-permeable area, said electron-emissive area being spaced from said anode by a greater distance than that between other portions of said cathode and said anode, maintaining said gas at a pressure in that region which, when multiplied by the length of the longest gap between said cathode and said anode, is below the Paschen minimum where insulating strength decreases with increasing values of the product of pressure times the length of the gap between said cathode and said anode, and subjecting the gas to an electric field under such conditions of electric stress that ionization by electron collision ensures, whereby the electron-emissive area of the cathode is bombarded by the resultant positive ions and the electrons released from the cathode by such bombardment and by ionization of the gas are accelerated to and through said electron-permeable area of the anode.

2. A method of irradiating coatings and other thin materials with energetic electrons, which method comprises enclosing a gas between a cathode having a multiplicity of electron-emissive areas and an anode having a corresponding multiplicity of electron-permeable areas said electron-emissive areas being respectively spaced from said electron-permeable areas by a greater distance than that between other portions of said cathode and said anode, maintaining said gas at a pressure in that region which, when multiplied by the length of the longest gap between said cathode and said anode, is below the Paschen minimum where insulating strength decreased with increasing values of the product of pressure times the length of the gap between said cathode and said anode, and subjecting the gas to an electric field under such conditions of electric stress that ionization by electron collision ensues, whereby electron-emissive areas of the cathode are bombarded by the resultant positive ions and the electrons released from the electron-emissive areas of the cathode by such bombardment and by ionization of the gas are accelerated to and through said anode.

3. A low dose rate high output electron beam tube, comprising in combination a source of negative high voltage power and a vacuumtight enclosure, said enclosure including a cathode electrode connected to said source and having a plurality of depressions comprising reentrant holes or slots in one of its surfaces extending over a large area and substantially filling said area, an anode electrode having a plurality of apertures extending over a large area and substantially filling said area, and an electron-permeable metallic membrane covering said apertures so as to complete the vacuumtight enclosure, said apertures being aligned with said depressions.

4. Apparatus in accordance with claim 3, wherein at least one intermediate electrode at a potential positive with respect to the cathode electrode is supported between the cathode electrode and the anode electrode.

5. Apparatus in accordance with claim 3, wherein at least one intermediate electrode at a potential controllable with respect to the cathode electrode is supported between the cathode electrode and the anode electrode.

6. A gas discharge device in which a multiplicity of parallel electron streams are produced and caused to pass efficiently through an aperture anode into a higher pressure gas by geometrically relating the cathode-anode structure such that a sufficiently long discharge path exists only in the selected apertured regions, comprising a cathode and an anode having nonuniform spacing and a gas therebetween at a pressure sufficiently below the Paschen minimum to limit discharge to the more remotely spaced portions of the cathode-anode gap.

7. Apparatus for irradiating coatings and other thin materials comprising means for producing a multiplicity of parallel electron streams, including a gas discharge device which contains gas at a pressure lower than that of its environment and which includes an apertured anode and a cathode, the geometrical relationship of the cathode-anode structure being such that a sufficiently long discharge path exists only in the selected apertured regions, whereby said electron streams are directed efficiently through said apertured anode, said cathode and anode having nonuniform spacing and a gas therebetween at a pressure sufficiently below the Paschen minimum to limit discharge to the more remotely spaced portions of the cathode-anode gap.

8. Modular apparatus for the irradiation of coatings and other thin materials, comprising at least one irradiation unit; each unit including a cathode surface capable of secondary electron emission and an electron-permeable anode window, the configuration of the apparatus being such that the longest electric field lines therein are those between said cathode surface and said window, said apparatus containing gas at a pressure such that ionization occurs predominantly between said cathode surface and said window, said cathode and anode having nonuniform spacing and a gas therebetween at a pressure sufficiently below the Paschen minimum to limit discharge to the more remotely spaced portions of the cathode-anode gap.

9. Apparatus for irradiating coatings and other thin materials with energetic electrons, comprising in combination an electron-emissive cathode, an electron-permeable anode, an enclosure containing gas at a pressure lower than that of its environment, said cathode and said anode being so situated that they are separated by said gas, said cathode and anode having nonuniform spacing and a gas therebetween at a pressure sufficiently below the Paschen minimum to limit discharge to the more remotely spaced portions of the cathode-anode gap, a power source adapted to impress a potential difference between said cathode and said anode of magnitude sufficient to cause ionization of said gas by electron collision and a current-stabilizing element connected in series between said power source and the current between said cathode and said anode.

10. Apparatus in accordance with claim 9, wherein said current-stabilizing element comprises a resistor.