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HIGH VOLTAGE ELECTRON TUBE

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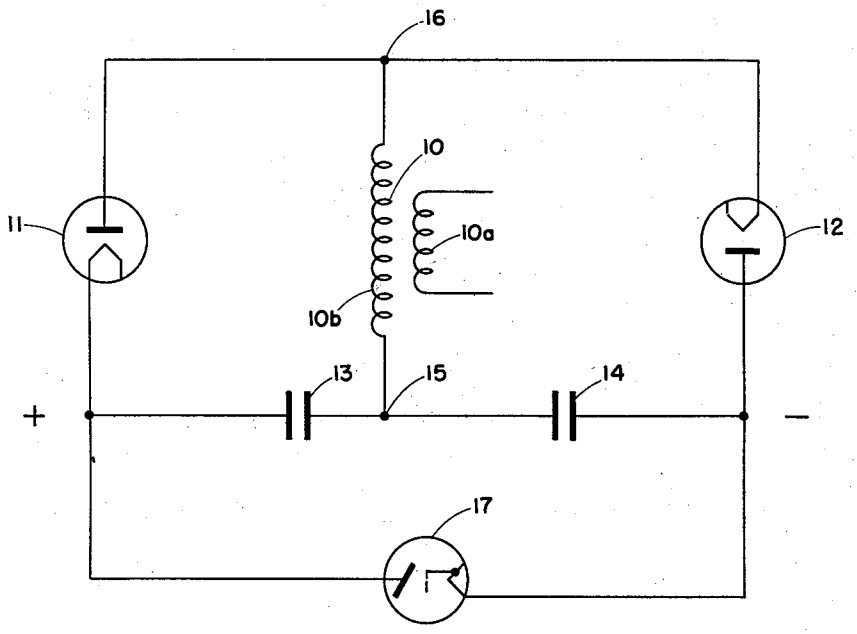


FIG. 1

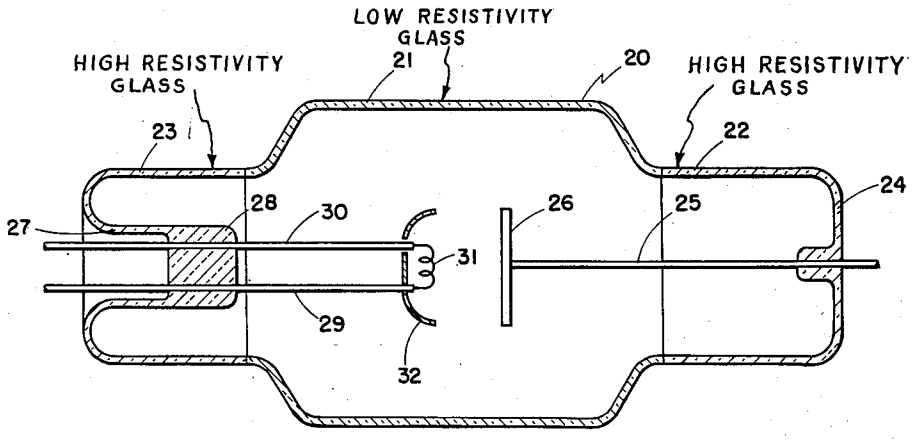


FIG. 2

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HIGH VOLTAGE ELECTRON TUBE

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This invention concerns a novel electron tube structure for use at a very high potentials. More particularly, this invention concerns the use of a novel tube envelope which makes it possible for electron tubes to withstand what have heretofore been considered highly adverse voltage conditions.

Deterioration of electron tubes operating at high voltages, particularly those materially in excess of 100 kilovolts, under certain conditions of operation, has presented a baffling problem to the electron tube industry. In particular, X-ray tubes and thermionic rectifier tubes for X-ray apparatus have shown rapid deterioration and short life. I have traced such deterioration and short life to bombardment of some portion or portions of the inner surface of the glass tube envelope walls by highly energetic particles which take random, uncontrolled paths through the vacuum space. These particles usually originate from some source within the tube in such a manner as to render their trajectories uncontrollable so that they have no part in the desired functioning of the tube. In those common cases, where the particles involved are electrons, the principal sources of such electrons are "cold emission" or "field currents" emitted from electrode structures subjected to high voltage gradients, and secondary electrons ejected from surfaces bombarded by purposely focused electrons at high velocity.

Such randomly moving high velocity electrons will continue to bombard glass surfaces lying in their trajectories, as determined by the electric fields present, until these surfaces, due to the accumulation of electrons thereon, become charged to a negative potential sufficiently high to prevent additional electrons from reaching said surfaces. If the potential of such a surface is raised to a value corresponding to the maximum energy of the randomly-moving electrons, then any such electron can arrive at such a surface only with zero energy and any additional electrons will be repelled. However, in high voltage tubes, such as X-ray tubes and rectifiers as normally constructed and operated, the charges which would accumulate on the envelope walls in this manner tend to leak away as rapidly as the bombarding electrons arrive. This leakage of charge occurs because the glass usually employed in the construction of such tubes is not a perfect insulator but has a finite resistivity, which is sufficiently low that, at the extremely high voltages employed in the X-ray service, appreciable conductivity exists. Hence, in operation, bombarding electrons continually arrive at the wall surfaces subjected thereto and leak away conductively so that additional bombarding electrons may replace them in a continuous cycle.

Deterioration will also occur where the tube wall has a tendency to acquire a high positive charge and thus attract to it electrons from tube elements which operate at low potential levels. Such electrons bombard the walls with destructive effects similar to those produced by the high-velocity electrons previously referred to.

The present invention is capable of eliminating or reducing tube deterioration due to bombardment of this

sort. Its theory of operation is as follows: If the rate of leakage of accumulated negative charge from the bombarded area or the rate of leakage of positive charges to the bombarded area can be reduced by a substantial amount, the rate of arrival of bombarding electrons will be limited correspondingly. Accordingly, this invention provides novel envelope constructions which serve to limit the rate of leakage between the area of the envelope normally bombarded and conductors penetrating the vacuum envelope.

More specifically this invention relates to the provision of a high voltage electron tube having a sealed envelope through spaced portions of which anode and cathode conductors extend, the spaced portions of the envelope through which the conductors extend being formed of a dielectric material having a higher resistivity than an intermediate portion of the envelope which receives electron bombardment and consequently accumulates a charge. The high resistivity of the spaced portions of the envelope is so controlled as to retard leakage of the charge by conduction from the intermediate portion of the envelope to the conductor by an amount sufficient to maintain the charge on the intermediate portion at a level which will minimize subsequent bombardment. The resistivity of the intermediate portion, however, is such that concentrations of the charge thereon will redistribute themselves and thus prevent buildup of localized charges.

The nature of my invention will be more clearly understood by consideration of an instance wherein the problem of envelope deterioration existed and wherein said problem has been solved. My complete analysis in this instance made it possible for the first time to recognize the specific causes of envelope wall bombardment in high voltage rectifiers. For the purpose of explaining my invention in light of this example of the bombardment problem, reference is made to the following drawings:

Fig. 1 illustrates schematically the circuitry for an X-ray machine of a type commonly referred to as a constant potential machine, which employs capacitors on which charge is imposed and maintained by means of a transformer and vacuum tube rectifiers.

Fig. 2 is a sectional view schematically illustrating a rectifier tube employing my invention, which tube may be employed as an element in the circuit of Fig. 1.

Referring to Fig. 1, the elements combined as shown represent a basic constant potential X-ray circuit. The transformer **10** is composed of primary winding **10***a* and secondary winding **10***b*. Rectifier tubes **11** and **12** are connected in series with capacitors **13** and **14**, respectively. Rectifier **11** and capacitor **13** are connected across the transformer secondary winding **10***b* at terminals **15** and **16**. Likewise, rectifier **12** and capacitor **14** are connected across the transformer secondary at terminals **15** and **16**. The capacitors both have one plate connected directly to one transformer terminal, here **15**, and the rectifier tubes both have one terminal connected to the other transformer terminal, here **16**. However, the anode terminal of rectifier **11** is connected to terminal **16**, whereas the cathode of rectifier **12** is connected to this terminal. X-ray tube **17** has its anode connected to the cathode of rectifier **11** and its cathode connected to the anode of rectifier **12**.

High potential is supplied the circuit of Fig. 1 through the secondary transformer winding **10***b*. The capacitor **14** will tend to charge up as electrons flow toward it from tube **12** so that even when tube **12** is not conducting the potential on the plate of the capacitor **14** connected to the anode of rectifier **12** and the cathode of X-ray tube **17** will be negative. In the same way, as electrons are conducted away through rectifier **11**, the plate of the capacitor **13** connected to the cathode of rectifier **11** and the anode of the X-ray tube **17** will assume a positive

potential. Thus an essentially constant negative potential will be maintained on the cathode and an essentially constant positive potential will be maintained on the anode of X-ray tube **17**.

It has been observed that a rectifier tube when used in the circuitry of Fig. 1, or some modification thereof, is subject to the deterioration described. More specifically, it has been observed that rectifier tube **11** located in the positive side of a circuit of this type deteriorates more rapidly than a similar rectifier tube **12** in the negative side of the circuit. The tube in the negative side of the circuit generally presents no more of a problem than rectifier tubes in pulsating potential machines.

Study of many such tubes which have become unserviceable reveals a characteristic condition in tubes from the positive side of the constant potential circuit which is recognizable as the result of bombardment of the glass walls of the tubes by high energy electrons. It is apparent that excessive bombardment of this type generates or releases gas leading to ultimate failure of the tube due to inadequate vacuum. An analysis attempting to explain why this condition should occur in the positive tube **11** and not in the negative tube **12** leads to the following conclusions:

The majority of the harmful bombarding electrons originate from points on the peripheral surface of the anode, being released by "field emission." Such emission and bombardment can take place only if there exists a large potential difference between the bombarded surface of the glass wall and the anode, with the anode negative with respect to the wall. In tube **12** the anode is held at a "constant" potential which is the maximum negative potential existing in the circuit. The glass wall being an insulator, the potential of its surface will depend on the sign and magnitude of charge deposited thereon. If at any time its potential should be positive with respect to the thermionic cathode, it would tend to draw electrons from the cathode, from which electrons are copiously available by "thermionic emission" and for which no large potential gradient is required. Hence, unless the cathode is completely shielded from the wall, the surface of the wall will quickly assume a potential approximately equal to the most negative potential attained by the cathode during the complete cycle of alternating voltage delivered by the transformer, which potential is approximately equal to that of the negative terminal of the capacitor **14**. Any slight leakage of charge from the wall will be immediately replaced during each cycle by electrons from the cathode at negligible velocity. Hence, the inner surface of the tube opposite the peripheral surface of the anode remains at essentially the same potential as the anode during all normal operation of the circuit, and no bombardment by field emission from the anode can take place.

In tube **11** on the other hand, the cathode is held at a "constant" potential which is the maximum positive potential existing in the circuit. The tube wall, therefore, will have no tendency to acquire thermionically-emitted electrons from the cathode unless its surface should by some means become positively charged to a potential higher than that of the cathode. The wall will, however, have a tendency to lose electrons by conduction to the cathode terminal since the conductivity of the glass is greater than zero. Conduction of electrons to the wall from the anode terminal will not offset this loss of electrons since the anode potential alternates between maximum negative and maximum positive, and hence the wall will tend to become positively charged with reference to the median potential of the system. Thus, when the anode potential swings negative, there will exist a potential difference between the peripheral anode surface and the inner surface of the tube wall of proper polarity and of a magnitude usually sufficient to give rise to field emission from points on the anode surface, resulting in bombardment of the wall by high-velocity electrons.

The leakage rate, in the case of conventional tube structures, is an inverse function of the specific resistivity of the glass of which the envelope is composed. For various reasons, it is customary to construct high voltage tubes of a species of boro-silicate glass having a specific resistivity ρ, at 250° C., in the order of 10^8 ohms per cm.^{3} (expressed as log $\rho=8$). More specifically, X-ray tubes are generally made of a type of glass designated in the trade as No. 774, for which log $\rho=8.1$. Rectifier tubes are usually made of No. 772, for which log $\rho=8.8$. In some instances, it has been adjudged advantageous to employ glass of still lower resistivity, for example No. 650, for which log $\rho=7.7$. In fact, one school of thought in the advancement of the high voltage tube art has followed a trend toward the use of lower resistivity glasses. The argument justifying this trend is to the effect that low resistivity glass permits concentrations of charge to leak away and thus avoids a build-up of localized charges to potential levels high enough to result in puncture of the envelope wall.

Despite the advantages of low resistivity glass for the envelope, such low resistivity glass has the disadvantage of permitting wall bombardment, as described above, to proceed uninhibited. In accordance with my invention, this disadvantage is eliminated or minimized by inserting as an integral part of the dielectric envelope a section consisting of dielectric material having a substantially higher resistivity value than the portion of the envelope which is most heavily bombarded. This integral section of high resistivity material is preferably inserted between an area subject to the objectionable bombardment and a conductor which penetrates the vacuum envelope and to which the charge may leak away. For example, see Fig. 2.

Fig. 2 shows schematically an electron tube diode employing my invention. Such a diode may be used for the rectifiers in Fig. 1 and is particularly useful for tube **11** to prevent its deterioration due to the effects mentioned above. The diode has a vacuum envelope generally designated **20**. The large diameter portion **21** of envelope **20** may be composed of material conventionally used for electron tube envelopes. The end portions and necks are composed of glass having a resistance of $10^{9.2}$ ohms per cm.^{3} or greater at 250° C. One end of the envelope is closed by vacuum wall **24** which is penetrated by rod-like conductor **25**. Anode **26** is supported on the end of rod-like conductor **25**. The other end of the vacuum envelope is terminated in a reentrant portion **27** terminating in a stem press **28** through which are sealed conductors **29** and **30**. Conductors **29** and **30** are terminated within the vacuum envelope by filament **31**. Cup-like member **32**, which provides a focusing means which focusses the electrons emitted by filament **31** toward the anode, may be affixed to conductor **29**.

I find it advantageous to employ for high resistance sections, such as necks **22** and **23** of the structure of Fig. 2, No. 707 glass, which has an expansion coefficient suitable to permit it to be sealed directly to No. 772, which, as mentioned above, is frequently used for high-voltage tube envelopes and which is advantageously employed as section **21** in the structure of Fig. 2. Log ρ for No. 707 at 250° C. is 11.2, indicating that its resistivity is approximately 300 times that of No. 772.

Other types of higher resistivity glasses may also be used for this purpose. For example, No. 7052 has a resistivity corresponding to log $\rho=9.2$, or about 10 times that of No. 774. This glass may be sealed directly to most of the lower resistivity glasses. No. 172 glass, having a log ρ value of 11.4, may be used by employing graded seal techniques well known in the art to incorporate it into an envelope structure.

To be effective, the length of this high resistivity section must represent a substantial portion of that part of the envelope intermediate the heavily bombarded area and the conductor. In most instances a substantial por-

tion of the envelope would include a ring section at least 2 centimeters long in the direction of charge leakage. More commonly the whole end of an envelope is composed of the high resistivity glass. For instance, where the tube's envelope is of generally tubular shape with necks of somewhat reduced diameter at opposite ends of the tube, these neck members may be composed of No. 707 glass. When one or both necks of the envelope are made of No. 707 glass, the rate of leakage of charge from the central or bombarded portion to a conductor which penetrates the envelope through an end portion at the remote end of the neck is greatly reduced.

The objective of this invention may frequently be achieved by a modified embodiment wherein the entire envelope rather than sections thereof is composed of glass in the higher resistivity category. Broadly, the advantages are achieved by virtue of the leakage paths between bombarded regions and terminals being composed of insulating material having a specific resistivity higher than $10^{9.2}$ ohms per cm.^{3} at 250° C. In those cases where lower resistivity in the bombarded region is not required for other reasons, the entire envelope may advantageously be composed of glass of high resistivity. An example of such a case is where, due to size or geometry, potential gradients at electrode surfaces are abnormally high when the total voltages and maximum potential levels are not sufficiently high to require the protection against puncture afforded by the lower resistance insulation in the envelope.

In another embodiment the entire envelope is composed of high resistivity material and the inner surface in the bombarded region is made slightly conductive by a thin coating of lower resistivity material. In examples of this embodiment, thin films of evaporated metals, and also vaporized silica, which has the property of becoming momentarily conductive when subjected to electron bombardment, are employed.

I claim:

1. A high voltage electron tube having an evacuated envelope of dielectric material and a conductor penetrating the envelope, the envelope comprising a first portion adapted to accumulate a charge when bombarded by electrons and having a specific resistivity of approximately $10^{7.7}$ to $10^{8.8}$ ohms per cm.^{3} at 250° C. whereby a charge accumulated thereon will tend to leak to the conductor, and a second portion of substantial length located intermediate the first portion and the conductor and surrounding the conductor and having a specific resistivity of at least $10^{9.2}$ ohms per cm.^{3} at 250° C. and being sufficiently higher than the specific resistivity of the first portion whereby leakage of the charge accumulated on the first portion will be retarded and the charge will be maintained substantially at a predetermined level.

2. A high voltage electron tube having an evacuated envelope of dielectric material and a conductor penetrating the envelope, the envelope comprising a first portion adapted to accumulate a charge when bombarded by electrons and having a specific resistivity of approximately between $10^{7.7}$ and $10^{8.8}$ ohms per cm.^{3} at 250° C. whereby a charge accumulated thereon will tend to leak to the conductor, and a second portion of substantial length located intermediate the first portion and the conductor and surrounding the conductor and having a specific resistivity of approximately between $10^{9.2}$ and $10^{11.4}$ ohms per cm.^{3} at 250° C. and being sufficiently higher than the specific resistivity of the first portion such that leakage of the charge accumulated on the first portion will be retarded and that the charge will be maintained substantially at a predetermined level.

3. A high voltage electron tube having an evacuated envelope of dielectric material and a conductor penetrating the envelope, the envelope comprising a first portion adapted to accumulate a charge when bombarded by electrons and having a specific resistivity of not more than $10^{8.3}$ ohms per cm.^{3} at 250° C., whereby a charge accumulated thereon will tend to leak to the conductor, and a second portion of substantial length located intermediate the first portion and the conductor and surrounding the conductor and having a specific resistivity of at least $10^{9.2}$ ohms per cm.^{3} at 250° C. and being sufficiently higher than the specific resistivity of the first portion whereby leakage of the charge accumulated on the first portion will be retarded and the charge will be maintained substantially at a predetermined level.

4. A high voltage electron tube having an evacuated envelope of dielectric material and a conductor penetrating the envelope, the envelope comprising a first portion adapted to accumulate a charge when bombarded by electrons and having a coating of a thin layer of conductive material on its inner surface whereby a charge accumulated thereon will tend to leak to the conductor, and a second portion of substantial length located intermediate the first portion and the conductor and surrounding the conductor and having a specific resistivity of at least $10^{9.2}$ ohms per cm.^{3} at 250° C. whereby leakage of the charge accumulated on the first portion will be retarded and the charge will be maintained substantially at a predetermined level.

5. A high voltage electron tube embodying an evacuated envelope of dielectric material, a first conductor penetrating the envelope at one end thereof, and a second conductor penetrating the envelope at the opposite end, the envelope comprising a first portion adapted to accumulate a charge when bombarded by electrons and having a specific resistivity of between approximately $10^{7.7}$ and $10^{8.8}$ ohms per cm.^{3} at 250° C. whereby the charge accumulated thereon will tend to leak to the conductors, and second and third portions of substantial length located respectively intermediate the first portion and the first and second conductors and surrounding the respective conductors, said second and third portions having specific resistivities of between approximately $10^{9.2}$ and $10^{11.4}$ ohms per cm.^{3} at 250° C., whereby leakage of the charge accumulated on the first portion will be retarded and the charge will be maintained substantially at a predetermined level.

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