May 12, 1959 SAMUEL T. YANAGISAWA 2,886,725

X-RAY TUBES

Filed July 22, 1955 2 Sheets-Sheet 1

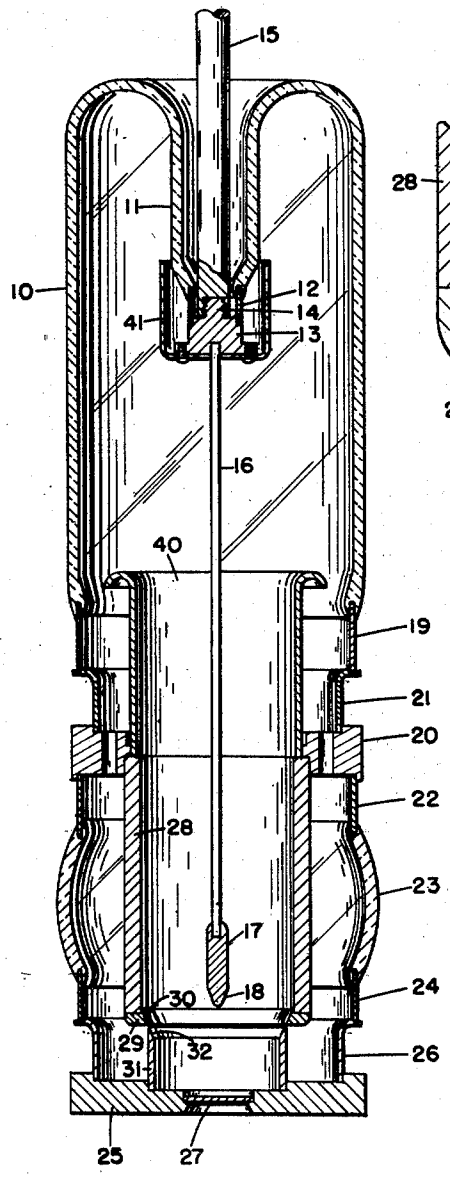


FIG. 1

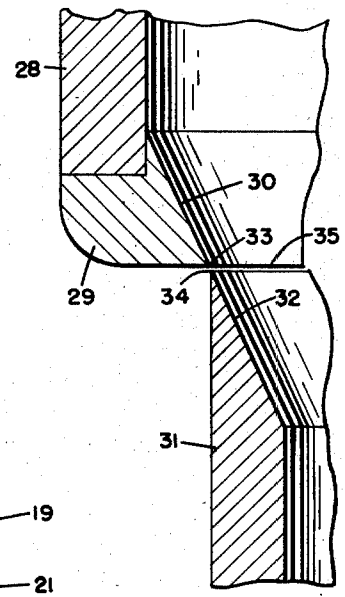


FIG. 2

INVENTOR.
SAMUEL T. YANAGISAWA
BY

ATTORNEYS

May 12, 1959 SAMUEL T. YANAGISAWA 2,886,725

X-RAY TUBES

Filed July 22, 1955 2 Sheets-Sheet 2

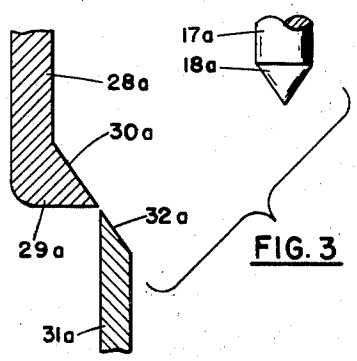


FIG. 3

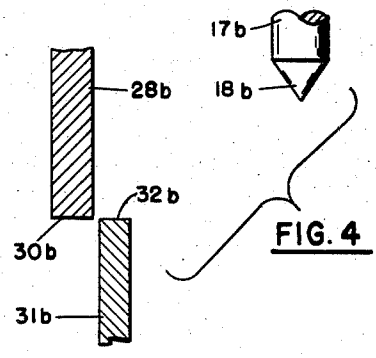


FIG. 4

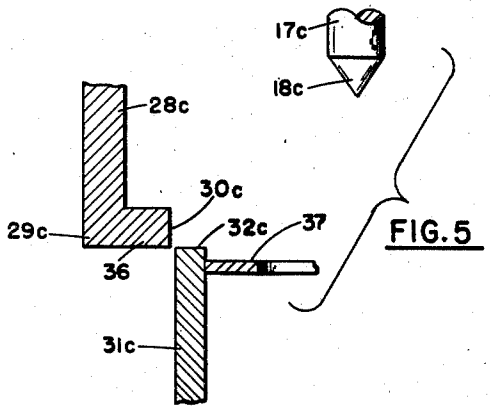


FIG. 5

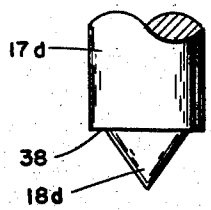


FIG. 6

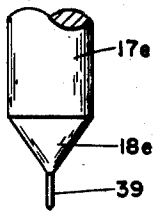


FIG. 7

INVENTOR.
SAMUEL T. YANAGISAWA
BY
ATTORNEYS

United States Patent Office 2,886,725 Patented May 12, 1959

2,886,725

X-RAY TUBES

Samuel T. Yanagisawa, Stamford, Conn., assignor to Machlett Laboratories, Incorporated, Springdale, Conn., a corporation of Connecticut

Application July 22, 1955, Serial No. 523,712

12 Claims. (Cl. 313—57)

This invention relates to X-ray tubes and has particular reference to improvements in flash X-ray tubes operated at fractional microsecond exposures.

A flash X-ray tube constructed in accordance with this invention has long life, produces a large number of very short duration pulses of X-rays which are consistent with respect to both duration and intensity, and produces an X-ray beam emanating from a relatively fine focal spot so as to produce a clearly defined image when used, for example, in high speed radiography.

Flash X-ray tubes constructed and operated in accordance with teachings of the prior art have not been entirely satisfactory, particularly because they failed after producing a relatively small number of short duration flashes. Some prior art flash X-ray tubes, for example, were able to produce small focal spots and pulses of relatively short duration, but were deficient in that they had a short life consisting of approximately twenty flashes. Since these tubes were relatively expensive, short life was a serious problem.

The presently described tube consistently produces several hundred separate fractional microsecond pulses, each roughly of .1 to .2 of a microsecond in duration, without warm up periods, so that the device is ready for immediate use when desired as in the investigation of high speed phenomena such as explosive detonations, high speed jets in shaped charges, projectile action, shrapnel distribution, physical action of armor piercing projectiles, and in many other applications.

A major factor contributing to short life of flash X-ray tubes is the problem of vaporization of tungsten caused by the tremendous rate of heat dissipation on the surface of a tungsten anode during the fractional microsecond of a tube's operation. These tungsten vapors generally accumulate on the inner walls and surfaces of the tube, including the window through which the X-rays pass. Such deposits on the window of course reduce the intensity of the X-ray beam. However, even more serious, the deposits of large amounts of vaporized tungsten on the inner insulating walls of the tube contribute to causing flashes of weak intensity and long duration. The deposits on insulating parts of the tube charge up and cause spontaneous or premature flashes and may also cause defocusing and misdirection of the electron beam. Deposits also shorten the leakage path between the anode and cathode to such an extent that the tube may flash along the wall between two electrodes, and may also form a conductive coating between the trigger and cathode electrodes so that a proper cathode arc can no longer be formed.

A distinctive feature of the present invention is that the electrode structure is arranged to direct the initial flow of electrons and resultant emission of vapor ions along desired controlled paths. I have found that the ionized tungsten vapor should move back toward the cathode emitting arc in order to create intense flashes of short duration. Tungsten vapor lowers the tube impedance very greatly and permits large currents to flow.

It also limits the duration of the discharge by lowering tube impedance and tube drop to such a point that the production of X-rays is terminated.

In the presently described tube design, the ionized vapor is constrained from depositing in large amounts upon any insulating surface by the inherent shielding effect of a novel coaxial type of construction and by a novel geometric relationship between the anode and cathode. The electrode structure is designed to focus the electrons emitted by the cathode onto the target of a conical anode and also shapes the electrical field in such a manner that most of the tungsten ions flow from the target directly back to the emissive area of the cathode. This is done by shaping the focusing surface of the cathode or anode in any one of several ways such as by providing the adjacent emitting surfaces of the cathode and trigger with bevels having surfaces lying substantially in a common plane parallel with the effective surface of the target, by providing the adjacent ends of the cathode and trigger with flat parallel surfaces which are located in stepped relation to form a focusing ring, or by providing the anode with a particular shape which will create the desired electrical field.

A further problem associated with many prior art flash tubes is that the trigger-cathode gap spacing is caused to be altered as a result of expansion of the parts during the exhaust cycle. The present invention embodies a tubular cathode member and a tubular trigger located in coaxial, substantially end-to-end relation with the trigger being of slightly smaller outside diameter than the inside diameter of the cathode member. When expansion occurs during the exhaust cycle, the cathode member and trigger are able to slide or telescope relative to one another and to subsequently return to their normal spaced relation without damage to the parts or upset to the desired space dimensions.

Therefore, it is accordingly a primary object of this invention to provide a long lived flash X-ray tube capable of producing a relatively large number of X-ray pulses of high intensity and of relatively constant fractional microsecond duration.

Another object is to provide a flash X-ray tube wherein vapor ions emanating from the anode during operation of the tube will be directed or attracted toward the vicinity of the cathode-trigger gap.

Another object is to provide a flash X-ray tube with a cathode of predetermined structural arrangement such that, upon operation of the tube, electrons emitted by the cathode are directed onto the effective portion of the anode and resultant ions emitted by the anode are directed onto the cathode.

Another object is the provision of a tube of the above character wherein the transit time for passage of tungsten ions from the anode to the cathode is controlled so as to permit operation of the tube for a controlled length of time before the ions arrive at the cathode in an amount sufficient to terminate the production of X-rays.

Another object is the provision of a flash X-ray tube wherein electrons are directed toward the active portion of an axially located conical anode by the effective emitting portion of a cylindrical cathode encircling the anode, and wherein a shaped electrical field is created for attracting vapor ions from the anode to the emitting portion of the cathode structure.

Another object is the provision in a flash X-ray tube of a cathode-trigger electrode arrangement the parts of which are capable of relative sliding or telescopic motion when expanded by heat during the tube exhaust cycle.

A further object is to provide a tube of the above character with improved shielding means to reduce de-

posits of vaporized target material on the inner walls of the tube.

A still further object is the provision of a flash X-ray tube of the above character which is relatively simple in structure and economical to manufacture.

Further objects and advantages of the invention will become apparent from the following description taken in connection with the accompanying drawings, in which

Fig. 1 is a longitudinal axial sectional view of a flash X-ray tube embodying a preferred form of the invention;

Fig. 2 is an enlarged fragmentary sectional view of adjoining portions of the cathode and trigger electrodes shown in Fig. 1;

Figs. 3, 4 and 5 are enlarged fragmentary views partly in section showing three different arrangements of cathode and trigger electrodes; and

Figs. 6 and 7 are enlarged fragmentary elevational views of the target portions of two anodes formed in accordance with this invention.

Referring more particularly to the drawings wherein like characters of reference designate like parts throughout the several views, the tube shown in Fig. 1 includes a dielectric envelope portion **10** which is provided at one end with a reentrant portion **11** through which is an axial opening having sealed to its periphery one end of a metal sleeve **12**. The inner end of the sleeve **12** is soldered to a block **13** which is provided with an outwardly extending threaded end portion **14** to which is removably connected one end of a conductive member **15**. The inner end of the block **13** carries one end of an anode supporting rod **16** which is preferably formed of molybdenum and which extends along the longitudinal axis of the tube toward the opposed end of the envelope. An anode **17** is secured to the free end of the rod **16** and comprises a cylinder of tungsten or like metal suitable for the purpose having a conical end portion **18** forming an effective target.

The end of the envelope portion **10** opposite the reentrant portion **11** has sealed thereto a cylindrical metal sleeve **19**. A cathode-supporting ring **20** has one end of second and third metal sleeves **21** and **22** sealed to opposite sides thereof, sleeves **21** and **22** being sealed to the ring **20** as part of a preassembled cathode structure which is subsequently vacuum sealed to the envelope by joining sleeve **21** to sleeve **19**. Sleeve **22** is likewise sealed to one end of a second dielectric envelope portion **23** having sealed to its other end a fourth sleeve **24**. A trigger electrode terminal is connected with sleeve **24** and consists of an apertured metal end portion **25**, formed preferably of copper, which has a fifth sleeve **26** joined to it, which sleeve **26** is vacuum sealed to sleeve **24** to complete the envelope assembly.

Within the aperture of end portion **25** is located an X-ray window **27** preferably of beryllium. The window **27** is vacuum sealed to its supporting structure by any suitable means well known in the art and is provided so as to permit exit of X-rays from the interior of the tube.

A generally tubular cathode **28** is secured at one end to the inner side of the cathode-supporting ring **20** and extends axially toward the end portion **25**. The extreme end of the cathode **28** is provided with an annular effective portion **29** which is formed with an inner surface **30** which is inclined with respect to the axis of the tube and to the walls of the cathode. The annular effective portion **29** of the cathode **28** may be formed as a separate annular member bonded to the end of the cathode **28** or may be an integral part of the cathode. The cathode **28**, including portion **29**, is preferably but not necessarily formed of nickel or molybdenum or a combination thereof.

Fixedly attached at one end to the inner surface of the tube end portion **25** is a tubular trigger electrode **31** having an outside diameter slightly smaller than the inside diameter of the cathode **28**. The other end of the trigger terminates adjacent the end of the cathode **28** in a beveled surface **32** adapted to be located substantially in a common plane with the inclined surface **30** of the cathode portion **29** (Figs. 1 and 2). This construction permits the trigger **31** and cathode **28** both to expand when heated, as during the baking process of the exhaust cycle. In such an event the trigger **31** will slide or telescope within the cathode **28** without damage to the adjacent sharp field emission edges **33** and **34** (Fig. 2) or upset to the normal predetermined gap spacing between the trigger and cathode. With this construction the trigger and cathode can be so located that the gap **35** between the field emission edges **33** and **34** can be maintained relatively small, preferably about .010 inch.

It is to be understood here that the cathode **28** and trigger **31** may be in reversed positions if desired.

A relatively large diameter cathode is required for the tube of the present invention, in the neighborhood of 2½" in inside diameter for example, since I have found that this aids in the production of desired intensity and hardness of the resultant X-ray flash to be formed by the tube. If we review the normal action of a flash X-ray tube we find that when suitable voltage is applied to the tube, as described hereinafter, an arc is created at the trigger-cathode gap and electrons that are pulled out of the trigger-cathode arc are accelerated toward the anode, and at the anode they produce heat which, in turn, vaporizes the anode surface and, as a result, ions are formed. Ions in the metal vapors are then accelerated back to the trigger cathode gap in accordance with this invention. It takes a certain amount of time to accomplish each of these steps. However, the time period that is most significant is the ion "transit time" or the time that it takes tungsten ions to get from the anode to the cathode. If we look at the time periods involved in other steps of this process, we find that it takes an extremely short time for electrons to get from the cathode-trigger arc to the anode, which time may be in the order of 10^{-10} seconds. It takes an extremely short time for these electrons to heat the anode surface to a temperature at which it will vaporize, which time may be in the order of 10^{-12} seconds. Then some undetermined extremely short time period is needed for this vapor to ionize. Finally there is the "transit time" necessary to accelerate the heavy ions of tungsten from the anode back to the cathode. This transit time is dependent upon the number of charges on the ions, and is further dependent upon the tube voltage, and the spacing between the electrodes. Assuming that the ions are singly charged in the present tube, this transverse interelectrode spacing between the anode and cathode at 120 kv. must be in the order of about 1¼". For other voltages, this spacing will vary. For lower voltages the spacing should be smaller, but for a general purpose tube it is believed that a cathode diameter of about 2½" is desirable. The cathode should be at least 1½" in diameter in order to function as desired and this is believed important because the transit time is in the order of magnitude of the duration of the X-ray flash as is shown by the fact that a cloud of tungsten ions arriving at the cathode from the anode terminates the production of X-rays. The space relation of the gap **35** to the anode **17** is, therefore, of considerable importance.

It is also necessary that electrons emitted by the cathode in the vicinity of the gap **35** be directed onto the conical surface **18** of the anode, which conical surface **18** should, therefore, be so located that it will receive the electron bombardment from the cathode.

However, the cathode structure may take any desired form, such as the inclined surfaces **30** and **32**, which will accomplish the objective of not only focusing electrons on the conical portion **18** of the anode but also create an electrical field which will draw toward it ions emitted by the anode when the tungsten or other material used for the anode is vaporized. The cathode **28**, and particularly portion **29**, as well as the trigger **31**, are accordingly shaped to create a field which will attract the vapor, or

more particularly the ions thereof, to the gap area of the cathode structure rather than allowing it to flow onto insulating walls of the tube and to accumulate thereon with undesirable effects.

In the operation of the tube, a positive high voltage is impressed upon the anode 17 from a suitable source by means such, for example, as a charged capacitor system (not shown) as is well known in the art. This high voltage is transmitted to the anode 17 through conductive member 15, block 13 and supporting rod 16.

Cathode supporting ring 20 also functions as a terminal which may be connected to a pulse transformer (not shown) in a manner similar to that shown and described in United States Patent No. 2,311,705 to C. M. Slack, and the tube metal end portion 25 likewise is connected to the transformer. With the high voltage on the anode 17, a pulse is applied across the cathode gap 35 between the field emission edges 33—34 at a predetermined instant. The resultant spark across the gap 35 developed between the field emission edges 33—34 causes the cathode to emit electrons which are directed toward the conical target portion 18 of the anode. The charged capacitor system then discharges along the rods 15 and 16, anode 17, and through cathode-anode interelectrode space to the cathode at ground potential. The target is heated by the high voltage discharge and, when bombarded by the electrons from the cathode, emits X-rays which pass out of the tube through window 27.

During the high voltage discharge and the electron bombardment of the anode, the tungsten material of the target 18 is heated to a temperature above its melting point, vaporizing a portion of the tungsten. Such vapor normally would become deposited on the inner walls of the insulating portions 10, 11 and 23 of the envelope to eventually function detrimentally to the successful operation of the tube. However, to prevent this condition, the cathode structure is designed to attract the vapor ions in the manner described hereinbefore. In this way the amount of vapor escaping into other portions of the tube is greatly reduced. A tubular shield 40 (Fig. 1) is mounted on the cathode-supporting ring 20 and extends axially of the tube toward the reentrant portion 11 to further prevent accumulation of tungsten deposits on the walls of the tube. This causes most of the relatively small amounts of vaporized tungsten which escape from the attraction of the cathode field to be deposited on the walls of the shield.

Mounted on the block 13 and covering the metal to glass seal between the envelope reentrant portion 11 and sleeve 12 is an inverted cup-like shield 41 which prevents stray electrons from bombarding the seal. The shield 41 also reduces the high electric field present at the seal.

While a specific cathode shape has been shown and described for creating a field which will attract vapor ions to the vicinity of the cathode-trigger gap, other examples of various cathode shapes suitable for this purpose are shown in Figs. 3, 4 and 5.

In Fig. 3 is shown a cathode structure which embodies a tubular cathode 28*a* which has an integral effective end portion 29*a* with an inclined surface 30*a* and a trigger 31*a* similar to that shown in Figs. 1 and 2. The relation of the cathode structure to the anode 17*a*, or more particularly to the effective conical target portion 18*a* thereof is clearly apparent.

In Fig. 4 a satisfactorily designed cathode structure is shown which embodies a cathode 28*b* and a trigger 31*b* which have flat adjacent ends 30*b* and 32*b* respectively lying in planes normal to the axis of the tube rather than inclined as in Fig. 3.

The structure in Fig. 5 embodies a cathode 28*c* which has an end portion 29*c* which is shaped as an inwardly turned flange 36. The inner end 30*c* of the flange 29*c* and the adjacent end 32*c* of the trigger 31*c* are flat and at right angles to each other. Near the end of the trigger 31*c* on the inner side thereof is an apertured disc 37 which functions to aid in focusing the electrons to the anode and attracting the vapor ions from the anode.

The anode may also be shaped to assist in the function of directing the vapor ions toward the cathode as shown in Fig. 6. In this structure the anode 17*d* is provided with a circumferential ledge or shelf 38 encircling the large end of the conical portion 18*d*. Another anode structure is shown in Fig. 7 wherein the small end of the conical portion 18*e* of the anode 17*e* is provided with an axial protuberance 39.

From the foregoing description it is apparent that an improved flash X-ray tube has been produced which has a long life and is capable of generating a large number of X-ray pulses, each of high intensity and fractional microsecond duration, in accordance with the objects of this invention.

While the novel features of the invention have been shown and are pointed out in the annexed claims, it is to be understood that various omissions, substitutions and changes in the construction and arrangement of parts shown and described may be made by those skilled in the art without departing from the spirit of the invention. Therefore, it is to be understood that all matter shown or described is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. A flash X-ray tube comprising a vacuum sealed envelope, an anode electrode structure within the envelope and embodying an anode disposed substantially on the axis of the tube, and an annular cathode electrode structure within the envelope in spaced encircling relation to the anode and comprising a tubular cathode member and a coaxial tubular trigger disposed in spaced end-to-end relation to provide a gap between their adjacent ends, said trigger and cathode member each being independently supported at a point remote from said adjacent ends and being of different diametric dimensions whereby they may telescope when heated and expanded.

2. A flash X-ray tube comprising a vacuum sealed envelope, an anode supported within the envelope on one end thereof, an annular cathode structure within the envelope in predetermined spaced encircling relation to the anode and comprising a tubular member supported at one end by the envelope and having at its other end an active cathode portion, and an annular trigger mounted on the end wall of the envelope opposite that end which supports the anode, the trigger being coaxial with and closely adjacent to the active cathode portion and having an outside diameter slightly smaller than the inside diameter of the active cathode portion whereby the trigger and active cathode portion may telescope under thermal expansion stresses.

3. A flash X-ray tube comprising a substantially cylindrical envelope embodying a hollow dielectric shell sealed at one end, an annular terminal sealed at one end to the other end of the shell, an annular dielectric portion sealed at one end to the other end of the annular terminal, a metal end wall positioned opposite the other end of the annular dielectric portion, and a substantially tubular seal connecting the end wall to the annular dielectric portion, an annular cathode mounted in the annular terminal and having a shielding portion extending freely longitudially within the annular dielectric portion and terminating within the tubular seal, and an annular trigger having one end terminating adjacent the free end of the cathode and providing therewith an electron emitting area, the adjacent ends of the cathode and trigger being of different diameters whereby they may telescope when heated and expanded during operation of the tube, the trigger further having a tubular shielding portion extending toward and mounted on said end wall, the shielding portions of the trigger and cathode completely isolating dielectric

portions of the envelope from the electron emitting area.

4. A flash X-ray tube comprising a vacuum sealed envelope, a conducting rod supported at one end within the envelope and extending along the longitudinal axis of the envelope, an anode supported on the free end of the conducting rod and having a conically-shaped target thereon, an annular cathode terminal mounted in and forming a circumferential portion of the envelope, an annular coaxial cathode structure positioned within the envelope in predetermined spaced encircling relation to the anode and having an emitting portion for bombarding the target with electrons, said cathode structure comprising a tubular member supported at one end by the annular terminal and having at its other end an active cathode portion, and a tubular trigger mounted on an end wall of the envelope and extending coaxially toward the active cathode portion and in close predetermined spaced relation therewith, the trigger having an outside diameter slightly smaller than the inside diameter of the active cathode portion whereby they may telescope when heated and expanded.

5. A flash X-ray tube comprising a vacuum sealed envelope, a conducting rod supported at one end within the envelope and extending along the longitudinal axis of the envelope, an anode supported on the free end of the conducting rod and having a conically-shaped target thereon, an annular cathode terminal mounted in and forming a circumferential portion of the envelope, an annular coaxial cathode structure positioned within the envelope in predetermined spaced encircling relation to the anode and having an emitting portion for bombarding the target with electrons, said cathode structure comprising a tubular member supported at one end by the terminal and having at its other end an active cathode portion, and a tubular trigger mounted on an end wall of the envelope and extending coaxially toward the active cathode portion and in close predetermined spaced relation therewith, the trigger having an outside diameter slightly smaller than the inside diameter of the active cathode portion whereby they may telescope when heated and expanded, the active cathode portion and adjacent portion of the trigger embodying means for attracting vapor ions from the target to the vicinity of the emitting portion upon bombardment and subsequent heating and vaporizing of the surface of the target.

6. A flash X-ray tube comprising a vacuum sealed envelope, a conducting rod supported at one end within the envelope and extending substantially along the longitudinal axis of the envelope, an anode supported on the free end of the conducting rod and having a conically-shaped target thereon formed of a material capable of copiously emitting X-rays when bombarded by electrons and simultaneously emitting vapor ions when heated by such bombardment to vaporizing temperature, an annular cathode terminal mounted in and forming a circumferential portion of the envelope, an annular coaxial cathode structure positioned within the envelope in encircling relation to the target and comprising a tubular member supported at one end by the annular terminal and having at its other end an active cathode portion, and a tubular trigger mounted on an end wall of the envelope and extending toward the active cathode portion and in predetermined spaced relation therewith to form therebetween a cathode-trigger gap of predetermined size, the cathode structure being adapted to emit electrons from the vicinity of the gap when suitable voltage is applied across the tube for bombarding the target, the trigger having an outer diameter slightly smaller than the inner diameter of the active cathode portion whereby they may telescope when heated and expanded, the active cathode portion and adjacent portion of the trigger embodying means for forming an electrical field which will attract the vapor ions from the target to the vicinity of the gap upon bombardment and vaporizing of the anode, and the interelectrode space between the gap and the target being of a predetermined dimension in accordance with the voltage across the tube and number of charges on the vapor ions whereby the transit time for passage of the vapor ions from the target to the vicinity of the gap is such that accumulation of ions at the gap will cause termination of the electron discharge at the conclusion of a predetermined time interval.

7. In a flash X-ray tube, an electrode structure comprising an anode, an annular cathode positioned in predetermined spaced encircling relation to the anode, and an annular trigger in spaced coaxial relation to the cathode providing therebetween a cathode-trigger gap for emission of electrons to the anode, the anode being adapted when bombarded by electrons to heat and form vapor ions, the inner surfaces of the cathode and trigger adjacent the gap lying substantially in a common plane angled with respect to the axis of the structure and forming an electrical field which will direct said vapor ions from the anode to the vicinity of the gap.

8. In a flash X-ray tube, an electrode structure comprising an anode, an annular cathode positioned in predetermined spaced encircling relation to the anode, and an annular trigger in spaced coaxial relation to the cathode providing therebetween a cathode-trigger gap for emission of electrons to the anode, the anode being adapted when bombarded by electrons to heat and form vapor ions, the adjacent end portions of the cathode and trigger being substantially tubular in shape with the outside diameter of the end portion of the trigger being slightly smaller than the inside diameter of the end portion of the cathode and the extreme ends of both of said portions being substantially flat and normally lying substantially in a common plane and thereby forming an electrical field which will direct said vapor ions from the anode to the vicinity of the gap.

9. In a flash X-ray tube, an electrode structure comprising an anode, an annular cathode positioned in predetermined spaced encircling relation to the anode, and an annular trigger in spaced coaxial relation to the cathode providing therebetween a cathode-trigger gap for emission of electrons to the anode, the anode being adapted when bombarded by electrons to heat and form vapor ions, the end portion of the cathode adjacent the trigger having an inwardly directed annular flange provided with a relatively flat end surface extending substantially coaxial of the structure, and the adjacent end portion of the trigger being substantially tubular and having an outside diameter slightly smaller than the diameter of the end surface of the flange, the trigger further having a substantially flat end normally lying substantially in a common plane with the adjacent peripheral edge of the adjacent end of the end surface of the flange and having an inner annular member spaced slightly from the flat end thereof for forming an electrical field which will direct said vapor ions from the anode to the vicinity of the gap.

10. In a flash X-ray tube, an electrode structure comprising an anode, an annular cathode structure positioned in spaced encircling relation to the anode and embodying an annular electron emitting gap for emission of electrons to the anode, the anode being a rodlike member having a conical active end portion for receiving the electrons and adapted thereupon to heat and form vapor ions, the anode further having a relatively flat annular portion encircling the conical end portion at its junction with the major portion of the rodlike member, the flat annular portion lying in a plane transversely of the axis of the structure and forming an electrical field which will direct said vapor ions to the vicinity of the gap.

11. A flash X-ray tube substantially as set forth in claim 1 wherein the cathode structure embodies means for shaping an electrical field which will direct vapor ions from the anode to the vicinity of the gap during operation of the tube.

12. A flash X-ray tube substantially as set forth in claim 2 wherein the anode structure embodies means for shaping an electrical field which will direct vapor ions from

the anode to the vicinity of the gap during operation of the tube.

References Cited in the file of this patent

UNITED STATES PATENTS

1,591,129 Holst et al. ---------- July 6, 1926
1,616,812 Lilienfeld ---------- Feb. 8, 1927
1,949,463 Forde ---------- Mar. 6, 1934
1,974,703 Bouwers ---------- Sept. 25, 1934
2,053,792 Huppert et al. ---------- Sept. 8, 1936
2,720,607 Criscuolo et al. ---------- Oct. 11, 1955