

Aug. 12, 1969

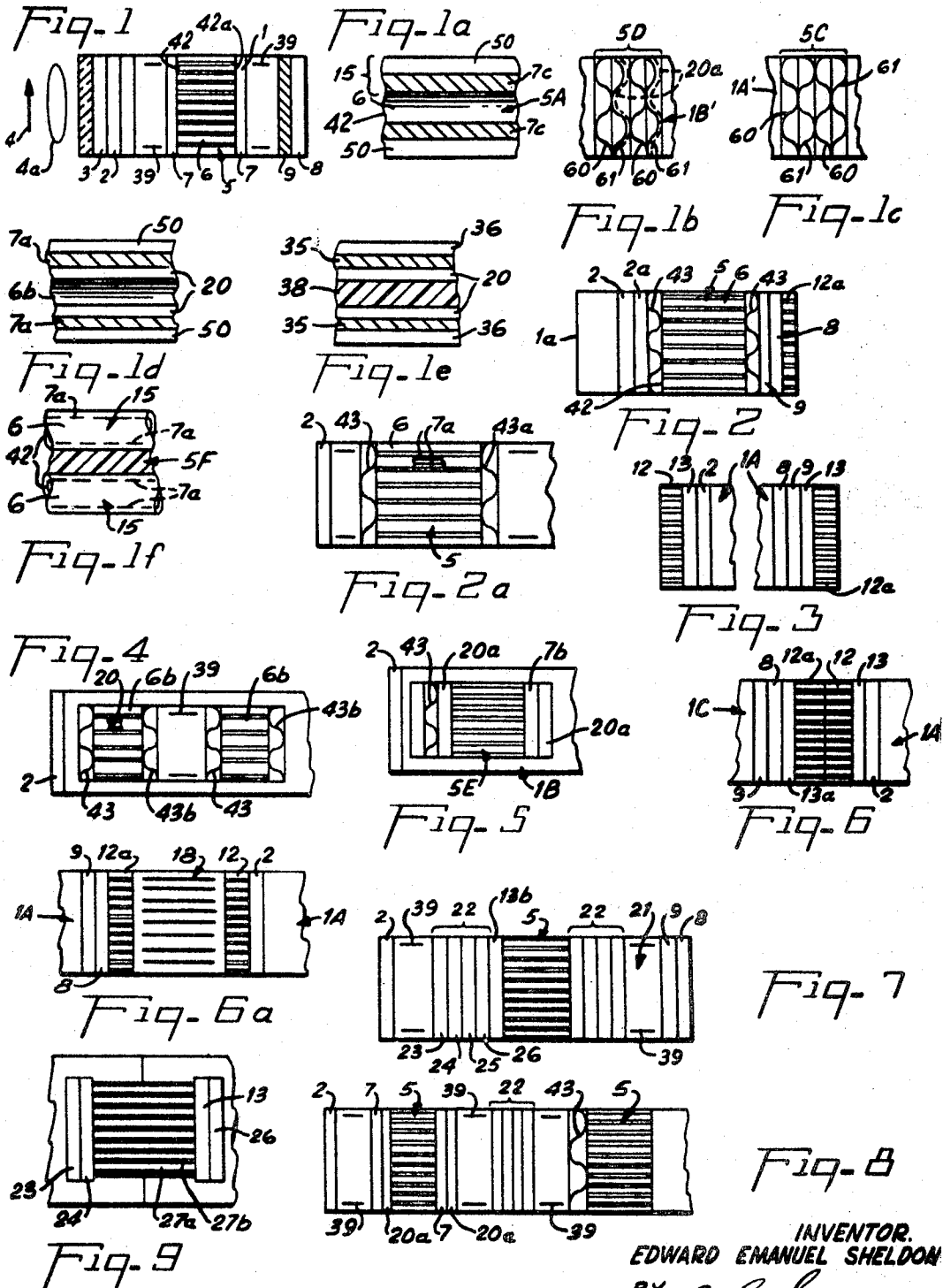
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3,461,332

VACUUM TUBES WITH A CURVED ELECTRON IMAGE INTENSIFYING DEVICE

Filed Nov. 26, 1965

4 Sheets-Sheet 1



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Fig. 10

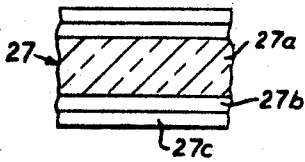


Fig. 10a

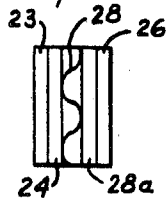


Fig. 11

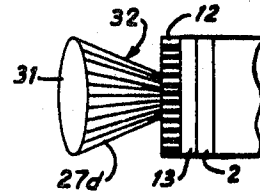


Fig. 12

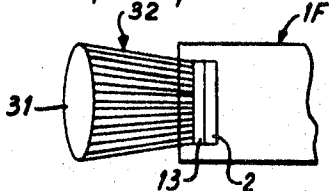


Fig. 13

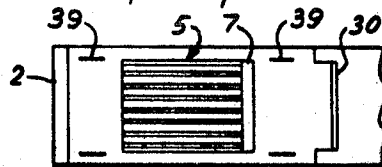


Fig. 13a

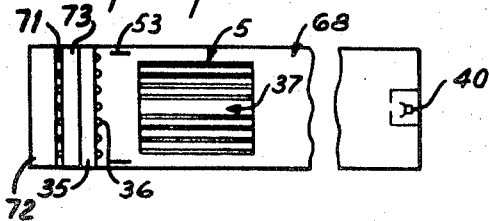


Fig. 13b

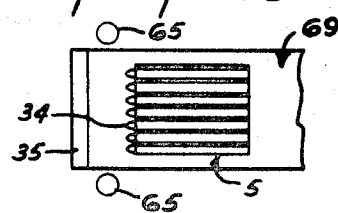


Fig. 14

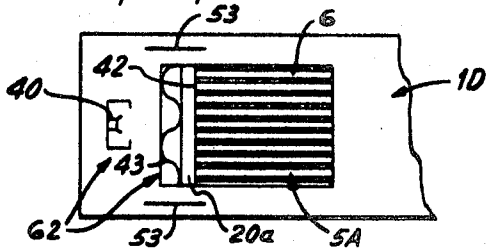


Fig. 15

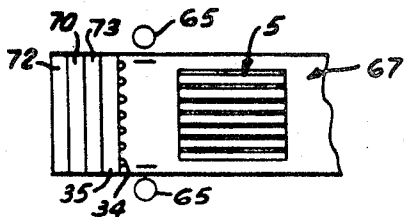
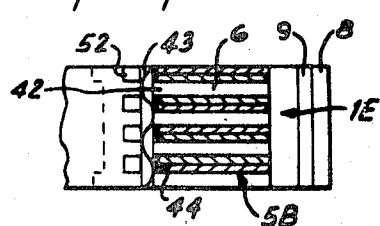


Fig. 13c

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FIG. 15d

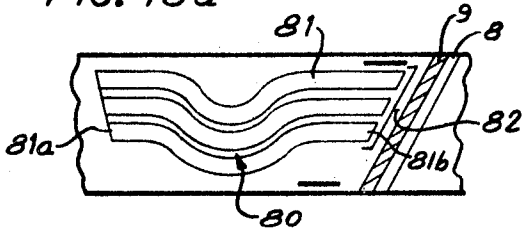


FIG. 15a

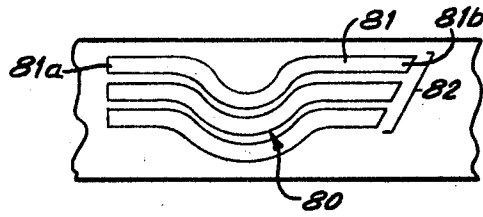


FIG. 15b

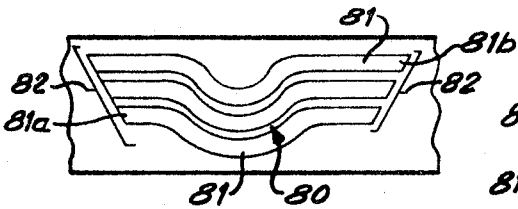
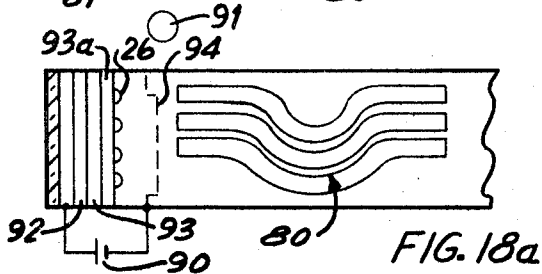
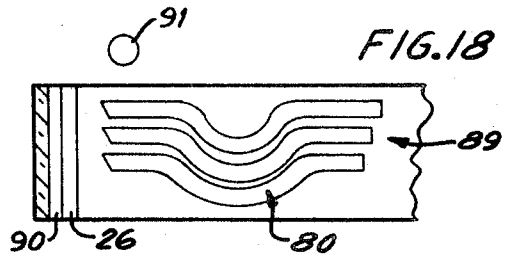
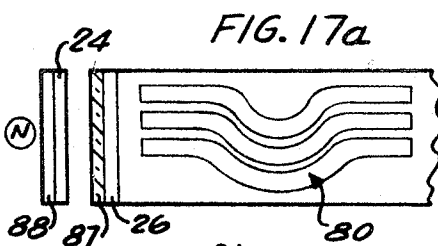
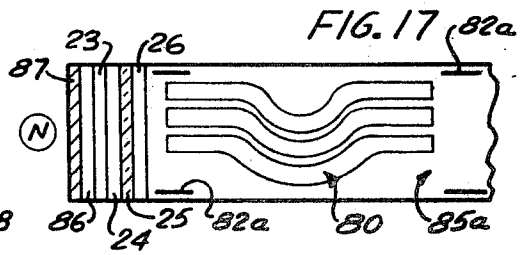
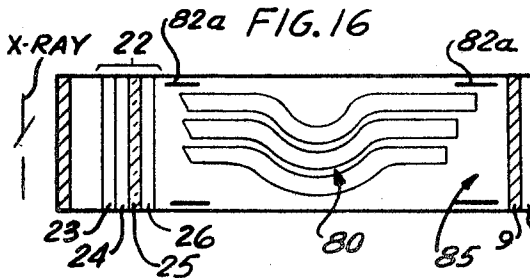
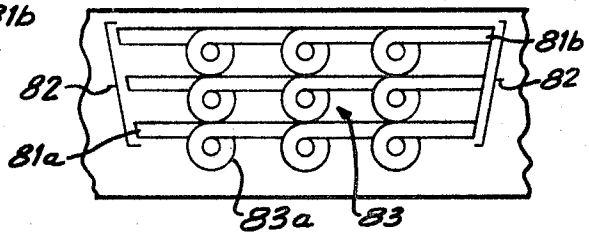


FIG. 15c



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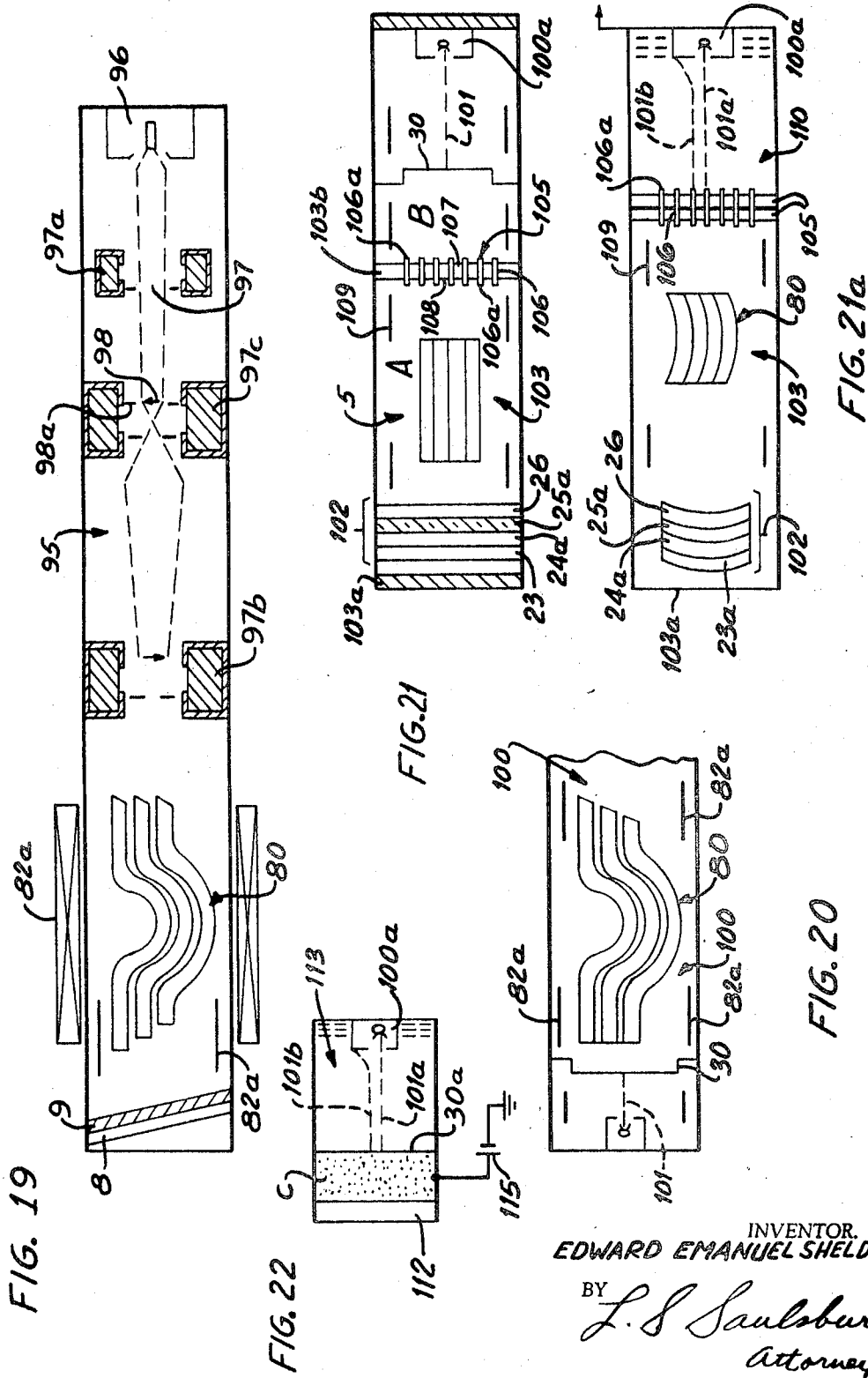
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3,461,332

VACUUM TUBES WITH A CURVED ELECTRON
IMAGE INTENSIFYING DEVICEEdward E. Sheldon, 30 E. 40th St.,
New York, N.Y. 10016Continuation-in-part of application Ser. No. 392,960,
Aug. 28, 1964, now Patent No. 3,400,291. This ap-
plication Nov. 26, 1965, Ser. No. 519,814

Int. Cl. H01j 31/26, 39/02

U.S. Cl. 313—65

15 Claims 10

ABSTRACT OF THE DISCLOSURE

This invention relates to novel vacuum tubes which serve for the intensification of images, which are of a high sensitivity and in spite of this sensitivity are free from spurious signals and can produce images of good contrast and definition. These results are due to the construction using a device comprising an array of plurality of curved electron multiplying hollow tubes which in addition prevents the instability of operation of said tubes.

This invention relates to the image converters and image intensifiers to be used independently or in combination with television camera tubes, kinescopes for black and white images, and for color images, radar kinescopes, electron mirror tubes, storage tubes and electron microscopes, and represents a continuation-in-part of my co-pending patent application Ser. No. 392,960 filed on Aug. 28, 1964 which is now U.S. Patent 3,400,291 issued Sept. 3, 1968, and has common subject matter with my U.S. Patent 3,279,460 filed Dec. 4, 1961 and issued Oct. 18, 1966; with U.S. Patent 3,149,258 filed Sept. 9, 1954 and issued Sept. 15, 1964; with U.S. Patent 3,021,834 filed Nov. 28, 1956 and issued Feb. 20, 1962; and with U.S. Patent 2,877,368 filed Mar. 11, 1954 and issued Mar. 10, 1959.

My invention will be useful in all situations which require the conversion of radiation from one wave-length to another wave-length of spectrum.

My invention will be useful also for intensification of the brightness of the images to be reproduced.

In addition, my invention is of great importance for improvement of resolution of images reproduced.

In addition, my invention will make it possible to miniaturize the present image converters, and image intensifiers, such as are described in my patents, U.S. 2,555,423 and 2,555,424; and which are used in the field of diagnostic radiology.

My invention will be better understood when taken in combination with the accompanying drawings.

In the drawings:

FIGURE 1 shows the novel image intensifier.

FIGURE 1a shows novel electron guide.

FIGURES 1b, 1c, 1d, 1e, and 1f shows modifications of the electron guide.

FIGURES 2, 2a, 3, 4 and 5 show modifications of the image intensifier.

FIGURES 6 and 6a show the use of two tubes in co-operative relationship.

FIGURES 7 and 8 show cascade image intensifiers.

FIGURES 9, 10 and 10a show a novel composite screen.

FIGURES 11 and 12 show image intensifier provided with a fiber-optic lens.

FIGURE 13 shows a novel television camera tube.

FIGURES 13a, 13b, 13c show novel acoustic image converters.

FIGURE 14 shows a novel electron gun.

FIGURE 15 shows a novel storage tube.

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FIGURE 15a shows a novel curved electron guide and multiplier.

FIGURE 15b shows a modification of the novel curved electron guide and multiplier.

FIGURE 15c shows a novel spiral electron guide multiplier.

FIGURE 15d shows image intensifier tube.

FIGURE 16 shows a novel X-ray image intensifier.

FIGURE 17 shows a neutron image intensifier.

FIGURE 17a shows a modification of neutron image intensifier.

FIGURE 18 shows a novel infra-red image intensifier.

FIGURE 18a shows a modification of infra-red image intensifier.

FIGURE 19 shows a novel charged particles microscope.

FIGURE 20 shows a television type of microscope.

FIGURE 21 shows an image intensifier with an image conductor.

FIGURE 21a shows a modification of the image intensifier with an image conductor.

FIGURE 22 shows another modification of an image intensifier.

FIGURE 1 shows a novel vacuum tube which comprises a photoemissive photocathode 2 such as of Cs, Na, K with Sb, Bi or As or of a mixture of aforesaid elements, such as K—Cs—Sb or Na—K—Sb. For infra-red radiation Cs—O—Ag or Cs—Na—K—Sb will be more suitable. The photocathode 2 may be deposited on the end-wall of the tube 1 or on a transparent supporting plate such as of quartz, glass or mica 3 or of arsenic trisulfide. The visible or invisible radiation image of the examined object 4 is projected by the optical system 4a on the photocathode 2 and is converted into a beam of photoelectrons, having the pattern of said image. The photoelectron beam has to be focused in order to get a good reproduction of the image. In the devices of the prior art, the focusing was accomplished by electrostatic or electromagnetic lenses which are large and heavy. As a result, the standard image tubes are bulky and cannot be miniaturized. In my device, I eliminated the electrostatic or electromagnetic lenses which made it possible to make a miniature device. The problem of focusing the electron beam without the use of electron-optical devices, was solved by the use of a novel mechanical device such as the apertured guide 5. The guide 5 comprises a plurality of tunnels 6, each tunnel is of microscopical diameter and extends through the whole length of the guide. Each of the tunnels must be insulated well from the adjacent ones. It was found that there are various ways to construct such guide. In one preferred embodiment the guide 5A may be constructed of a plurality of hollow tubes 15 of glass or of plastic, having their both ends open and being of ten microns diameter or less, and held together by silicone or other temperature stable plastics or by fusing them together by heating, see FIGURE 1a. For a good resolution of the image, I use 150–250,000 of such tubes stacked together in one square inch area. In some cases each of tubes 15 is coated on inside walls with a conducting layer, such as of aluminum, 7a or semi conducting layer 7c, which is connected to an outside source of electrical potential.

The tubes 15 may be also held in position at their ends only either by fusing them at the ends only, by heat, or by gluing them together with silicone or other plastic material compatible with vacuum or mechanically, for example, by threading their ends only into a mesh screen mounted rigidly in the tube.

In cases in which resolution of images is not important, the guide 5 may be constructed of a number of apertured glass plates combined in one unit as was described above for tubes 15. In the preferred embodiment of invention

the tubes 15 of glass or plastic may be coated on their outside walls with a conducting material 7a or semi-conducting material 7c and next with the insulating material such as of fluorides, glass, plastic, MgO, or silicon oxide 50, extending along the entire length of said tubes and around their entire circumference. Next the inner glass or plastic wall of the tubes 15 is leached out to make the conducting 7a or semi-conducting layer or resistive 7c face the lumen of the tunnels 6. In this construction the insulating coating 50 is of material resistant to the leaching agent and it will serve as a support for other layers. The material for uniting the tubes 15 should be resistant to temperature necessary for vacuum processing. Plastic materials such as fluoro-carbons, polyethylenes such as fluoroethylenes or silicon compounds such as silicates are useful.

If the tubes 15 are united by heating them, the outer walls of the tubes may be clad before the fusion with a glass or other material which is resistant to the leaching agent and which melts easier than the layer 50. In some cases the dielectric layer 50 may serve for this purpose as well.

In some cases, the first coating to be applied to the walls of the tubes 15 may be of a secondary electron emissive material 20, as shown in FIGURE 1d, which may be of semi-conducting type such as CsSb, of insulating type such as of fluorides, MgO, or alkali halides such as KCl or of aluminum oxide, or of conducting type such as Be, Ni, Cu, or of a mixture thereof. In some cases layer 50 and 7a or 7c should be able to tolerate temperature of 600° C. The dielectric layer 50 as was explained above serves as a support for all other layers and extends along the entire length of the tunnels.

The secondary electron emissive layer 20 should preferably extend along the entire length of the tubes and cover the inside lumen of tunnels 6 on all sides.

In some cases the coating 20 may be also applied to the inside walls of the tubes 15, after they have been coated with the conducting and insulating layers and after they were leached as was described above, but the results are inferior than in the method described above.

It is also possible to coat the inside walls of the tubes 15 with a conducting layer and with a secondary electron emissive layer 20 by evaporation or electrolytically. In such case the tubes 15 do not require any leaching at all. The results however are inferior to the method described above because the secondary electron emissive coating is not uniform. In one embodiment of preferred construction the deposition of the secondary electron emissive material is done on the external surface of the walls of said tubes which makes it practical to produce a homogenous and uniform deposition of the secondary electron emissive material. As was explained above the subsequent leaching of the glass makes the secondary electron emissive material face the lumen of the tunnels 6b.

Another preferable method of building the guides 5 is to use a fiber plate which consists of plurality of fibers of 5 to 10 microns diameter made of glass or plastics.

The fibers are coated with a dielectric material 50 such as a suitable glass, plastic, fluorides, silicon oxide or other silicon compounds, as shown in FIGURE 1f. In some cases the fibers and their coating should be able to tolerate temperature of 600° C.

The material for uniting the fibers should be resistant to leaching agent used for the glass and also resistant to temperature necessary for vacuum processing. Among plastic materials fluoro-carbons, polyethylenes such as fluoroethylenes or silicon compounds are the best. All these fibers are glued together chemically or are fused together by heating. Such a fiber-plate is now subjected to a leaching process in which the glass or plastic fibers are etched out and dissolved by a suitable chemical. The leaching agent does not attack however, the coating of fibers. We will obtain therefore, after the leaching is completed, a guide 5f having as many tunnels 6 as there were original fibers in the plate. The fiber-plates can be constructed of fibers having only six microns in diameter. Therefore

the tunnels 6 will have a diameter of approximately 6 microns. If it is important to have the tunnels of a uniform diameter, the fiber plate should be made of fibers which have a coating of glass or plastic which does not deform during the heating fusion. In some cases it is preferable to have an electrically conducting coating on the inside walls of tunnels 6. In such case, a layer of Al, Pd, Au or Ag may be deposited on the inside walls of the tunnels 6 either by evaporation or electrolytically. A preferred method of providing a conducting 7a or semi-conducting or resistive 7c coating inside of tunnels 6 is to use the fiber plate in which the fibers before combining them in one unit are clad with a metallic coating or in which the dielectric coating such as of glass or plastic comprises a metal.

In such case an additional insulating layer 50 which may be of a glass, plastic, fluorides or silicon oxide or silicates should be deposited outside of the metallic layer to provide a good electrical insulation of tunnels 6 from each other. It should be understood that tunnels 6 and all their modifications have the length a few times, which means at least two times, larger than the diameter of their apertures 42.

Also fiber-optic mosaics may be used for construction of the electron guide 5. Such mosaic can be made of a plurality of fibers, having a core of one kind of glass and a coating of another type of glass. All these fibers are fused together by heating. Such a fiber-optic plate is now subjected to a leaching process in which the core of the fibers is etched out and dissolved by a suitable chemical. The leaching agent does not attack however, the coating of fibers. We will obtain therefore, after the leaching is completed, a plate having as many tunnels as there were original fibers in the fiber-optic mosaic. It should be understood that these glass fibers and fibers described above may be also provided with a coating of secondary electron emissive material 20 and of the conducting material 7a before being coated with another type of glass. Therefore after the core of said fibers is leached out the secondary electron emissive layer will face the lumen of tunnels 6.

I found that the tunnels made of the metal tubes in the prior art could not give a good resolution of the images because the metal tubes could not be made of diameter smaller than 0.50 mm. and could not be reproduced uniformly. In my device glass or plastic tubes are used which can be produced of diameter of 0.01 mm. and which can be produced with a great degree of uniformity in great numbers. My device will need 200,000 tubes or more.

It should be understood that the word "glass" in the specification and in the claims embraces all kinds of glasses and synthetic plastic materials as well.

Another electron guide is shown in FIGURE 1c. The vacuum tube 1A' has a source of electrons such as photocathode 2 or an electron gun 40 and a novel electron guide 5C.

The guide 5C comprises in vacuum tube 1A' a plurality of perforated members 60 such as plates or meshes of dielectric material, such as glass or plastic and a plurality of electrically conducting perforated members 61 such as plates or meshes of steel, nickel or copper. The dielectric members 60 and conducting plates or meshes 61 are stacked together and glued together or fused in an alternating pattern. In this way plural tunnels 6a are produced which have walls of alternating strips of dielectric material and of a conducting material. All electrically conducting members 61 may be connected to an outside source of potential.

An improved method of producing apertured plates or meshes is to use a fine focused electron beam for perforating continuous sheets of suitable materials. This method is used for electrically conducting materials such as nickel, copper beryllium and for dielectric materials such as plastics, fluorides or glass as well.

In some cases it is advantageous to intensify electron beam by a secondary electron multiplication. This is accomplished in my invention by coating the perforated apertured conducting members 61 of the guide 5D in vacuum tube 1B' with a secondary electron emissive material 20a such as calcium fluoride, alkali halides, such as KCl, aluminum oxide, CsSb, and Ni or Be, of the thickness of 50 to 250 angstroms as shown in FIGURE 1b. This coating 20a may be deposited by evaporation or by electrolytic process, and is deposited before the members 60 and 61 are combined together in one unit, their apertures being aligned and forming thereby elongated tunnels 6a having the length larger than diameter of said apertures. It should be understood that the various arrangements of dielectric members 60 and of conducting members 61 coated with layer 20a come within the scope of my invention. For example, I may use a few dielectric members 60 for each conducting member. The conducting members 61 coated with the layer 20a are connected to an external source of the electrical potential. Each member 61 is provided with a potential a few KV higher than the preceding one. In the vacuum tubes of the prior art the emitted secondary electrons had to be focused by means of bulky magnetic devices to prevent loss of resolution. In my device, all electron-optical focusing devices can be eliminated and still a better resolution is obtained than in the prior art. The secondary electrons must travel through the tunnels 6a and are restrained to the size of such tunnels. The tunnels 6a or 6 should preferably be in some cases at an angle to the photocathode 2. In some cases the apertures 42 of tunnels 6 or 6a should have a bevelled shape.

It was found however that the perforated plates of meshes whether of conducting type or of dielectric type cannot give as good resolution, as the electron guides made out of hollow tubes or of fibers which were described above. It was also found that conducting mesh screens covered with insulation and stacked together do not make tunnels of uniform diameter and shape as it is required for the best resolution of the images as it is impossible to bring plurality of such screens into a perfect registry with each other as it was successfully done in electron guides using hollow tubes or leached out fiber-plates.

My novel imaging devices may use all embodiments of the electron guides described above. The novel image tube 1 shown in FIGURE 1, as described above, has the photocathode 2 on the support 3, electron guide 5 and an image reproducing screen 8. The image reproducing screen 8 comprises luminescent or electroluminescent material such as ZnCdS, ZnSAg or zinc silicate and is covered on one side with an electron transparent, light reflecting layer 9 such as aluminum. The layer 9 prevents the light emitted by the screen 8 to scatter back to the photocathode 2. The image of the examined area 4 is projected by the lens 4a on the photocathode 2 and is converted into a beam of photoelectrons having the pattern of said image. The photo electron beam is accelerated by the electrical fields 39, enters the guide 5 through the apertures 42 and is focused by said guide onto luminescent screen 8. It leaves the guide through the apertures 42a, is accelerated again by the fields 39, strikes the screen 8 and reproduces a visible image therein. This novel image tube does not require any electron-optical focusing devices for good resolution of the image.

I found that the closer, the guide 5 is to the photocathode 2, the better is the resolution of the image. In particular, a distance of a small fraction of one millimeter will give the best results, the distance of a few millimeters will give a much worse resolution. The vacuum tube 1 shown in FIGURE 1 must be provided with a uni-directional electrical potential for acceleration of photoelectrons from the photocathode to the guide 5, and from the guide 5 to the image reproducing screen 8. The accelerating potential may be applied to the conducting

cylinders which transmit electrons or coating 39 on the inside of the tube envelope or to the conducting layer 7 such as of aluminum. The higher the accelerating potential is, the brighter the reproduced image will be in the screen 8. There is, however a limit to the strength of the accelerating potential which is set by the dielectric strength of the tube. The use of guide 5 allows the potential to be spread between the photocathode 2 and screen 8 over a longer distance and without loss of resolution. Therefore it will be possible now to use, in the tube 1, a much higher potential than it would be feasible without said guide 5. The conducting layer 7 may be 50-100 A. thin so it will be completely transparent to the photoelectrons emitted by the photocathode 2. The conducting layer 7 or semiconducting layer 7c is connected to an outside source of potential and may be preferably in contact with the conducting or semiconducting coating on inner walls of tunnels 6. The layer 7 may be continuous. In some cases, a perforated metallic layer 7b will be better. The perforations in the layer 7 corresponding to the apertures 42 of the tunnels 6, may be made by blowing a strong current of air through the tunnels 6. Another method of producing the apertured conducting member is to use a perforated plate or mesh screen of conducting material such as 43 described below.

The length of the tunnels 6 in the guide 5 must be longer than the diameter of the apertures 42 of said tunnels. The actual length will vary according to the application of my guide and the type of vacuum tube. However the tunnels of the guide should be at least a few times longer than the diameter of the apertures. The longer is the guide 5, the greater difference of potential can be applied to both sides of said guide. The greater is the potential difference, the more acceleration of the electrons can be achieved. This brings about a greater image intensification, which was one of the purposes of my invention. The acceleration potentials may be supplied from an external source of potential connected to the layer 7 or 43 or to separate grids which transmit electrons and are disposed on both sides of the guide 5, or to conductive rings 39 mounted on the walls of the vacuum tube. In the devices of the prior art, it was impossible to provide a large potential difference, because the separation of the fluorescent screen 8 from the photoelectric screen 2 could not be longer than 0.25-0.5 cm.; exceeding this distance caused a prohibitive loss of resolution of the image. In my device, in spite of the elimination of the focusing electron-optical lenses or fields, I can provide separation of the photocathode 2 and of the fluorescent screen 8 of any desired length without a loss of resolution of the image. I found that for the best resolution in this embodiment of invention the walls of the tunnels 6 facing the lumen of said tunnels should be free from a photoelectric material or from a secondary electron emissive material.

The electron beam from the photocathode 2 carrying the image is therefore guided by the electron guide 5 to the image reproducing screen 8. It is accelerated to impinge on said screen 8 with a sufficient velocity to produce therein a visible image of increased brightness.

The tunnels 6 may be uniform in their diameter through the whole length of the guide 5. The tunnels 6 may have also a divergent form, in which the exit apertures are larger than the entrance apertures. In such case the electron beam will be enlarged upon its exit from the guide. The tunnels 6 may be also of a convergent form in which the exit apertures are smaller than the entrance. In this case the electron beam will be demagnified on its exit from the guide.

The separation of guide 5 from the photocathode 2 will cause some photoelectrons to strike the solid parts of guide 5, instead of entering the apertures 42 in the guide. In this way, a space charge may be produced on solid parts of guide 5, which may interfere with the photoelectron image. I found that development of the space charge is the cause of failure of such devices. The conducting

layer 7 will prevent this from happening as the charges will be able to leak away through layer 7. In some cases, it is preferable to mount guide 5 in contact with the photocathode 2 or the photocathode may be deposited directly on the end-face of guide 5 instead of on the end-wall of the tube or on a supporting member 3, as is shown in FIGURE 2. In this construction the conducting layer should be a perforated layer 7b or a perforated member 43. The discontinuous electrically conducting layer 7b may be also made by evaporation and will have 80-90% transmission for electrons. In some cases it is preferable to use an electrically conducting member 43 in the form of a metallic wide mesh screen or perforated plate of metallic material or of a perforated member coated with an electrically conducting material such as tin oxide. The member 43 is mounted on the end-face of the guide 5 in such a manner that openings of the screen or plate 43 coincide with one or with a few apertures 42 of the guide 5. The screen or mesh 43 is connected to an outside source of electrical potential in the same manner as layer 7b. In this construction I found that a problem arises because of the chemical interaction between the photoemissive material of photocathode 2 and the materials of guide 5. It is important, therefore to select materials which do not poison the photocathode. Lanthanum glass is chemically compatible. Still a protecting separating layer 2a of a light transparent material such as of calcium fluoride, MgO, or of silicon monoxide may be needed. The layer 2a should be preferably perforated and have a transmission for photoelectrons of 80%-90%. The aperture of the layer 2a must coincide with the apertures 42 of the guide. The layer 2a may be prepared by deposition on the top of the layer 43 of a continuous layer first and next by rupturing said layer with a strong current of air blown through tunnels 6, so that only the parts overlaying the solid portions of the guide 5 will remain in position.

Also, the phosphor screen 8 may be deposited directly on the end-face of guide 5. This construction facilitates markedly the construction of tube 1, as guide 5 with the image reproducing screen 8, and in some cases also with the photocathode 2 may be prepared outside of vacuum tube 1, and then introduced into tube 1a in one unit, and mounted therein.

In some cases, either only the photocathode 2 or only the image screen 8 are in contact with the guide 5. In case the screen 8 is separated from the guide 5, the separation, for the best results, should be preferably a fraction of one millimeter.

In some cases it is preferable to prevent the electrons which travel through the tunnels 6 or 6a in the guide 5 from striking the walls of said tunnels. This can be accomplished by providing the walls of said tunnels which face the lumen with a conducting or semi-conducting coating 7c as shown in FIGURE 2a. The conducting coating may be of aluminum or chromium. The semi-conducting coating may be of tin oxide or of titanium oxide. The coating 7a may be connected to the perforated conducting member 43 or to layer 7 which again may be connected to an outside source of electrical potential. As all tunnels 6 are in contact with the layer 7 or with member 43, walls of said tunnels will have a potential which will repel electrons travelling through said tunnels.

In some cases, the second perforated member 43 or 7 mounted on the opposite end of the guide 5, may be discontinuous from the coating 7a by terminating said coating 7a before reaching one end-face of the guide 5. In this construction, the second member 43 may be connected to the external source of electrical potential to provide acceleration for electrons.

In the embodiment of invention, shown in FIGURE 1 and 2, and 2a, the tunnels 6 of the guide 5 run normally to the photocathode 2 and are straight from the beginning to their end to prevent photoelectrons from striking the inside walls of the tunnels.

It will be understood that my device may use a plurality of electron guides 5. In such case electron accelerat-

ing means such as grids, rings, cylinders or meshes connected to a suitable source of potential may be interposed between the electron guides.

The semi-conducting coating or resistive 7c in some cases is preferable to conducting coating because it allows to establish potential gradient along the length of the tunnels 6. This potential gradient will cause acceleration of electrons into direction of the exit apertures 43a if it is connected to a suitable source of electrical potential.

In many cases it is advantageous to intensify electron beam by a secondary electron multiplication e.g. by coating the inner walls of the tunnels 6a with a secondary electron emissive material 20 such as CsSb, Ni, Be, calcium fluoride, alkali halides such as KCl or aluminum oxide or others. This coating 20 may be deposited by evaporation into tunnels 6, but the deposition is not uniform for the best results. In a preferable modification of this invention the secondary electron emissive coating 20 for the inner walls of the tunnels 6 may be provided by the methods which were described above. The glass or plastic fibers 38 before being fused or glued into a fiber-plate are coated with a secondary electron emissive material 20, such as was described above. On the top of said coating 20 an electrically conducting coating 35 is applied, such as of chromium, aluminum or nickel. On the top of the conducting coating 35, a dielectric coating 36 such as of glass, plastic or of fluorides is applied, which will serve to fuse all fibers into one fiber-plate as shown in FIGURE 1e. It should be understood that the coatings 20, 35 and 36 must be of material resistant to the action of the chemicals used for etching out the fibers. After the fiber-plate is prepared, and the fibers are leached out, we obtain the tunnels which have the following layers. The layer facing the lumen of said tunnels is the secondary electron emissive layer 20, the next layer is the electrically conducting layer 35, the next layer is the insulating layer 36. The conducting layer 35 may be connected to the source of suitable potential for the best secondary electron emission. The conducting layer 35 may be also mounted on the outside surface of the insulating layer 36 instead of being on the inside surface.

In some cases, instead of conducting layer on the inside walls of the tunnels 6 it is better to have a layer of semi-conducting material 7c such as of tin oxide, titanium oxide, or zinc fluoride. It should be understood that the use of semi-conducting coating 7c instead of a conducting coating applies to all modifications.

Instead of using a separate conducting coating 35 or semi-conducting coating 7c, the glass forming the walls of tunnels 6 may be of semi-conducting type such as having electrical resistance not less than 10^7 ohm and not higher than 10^{11} ohm and will serve then as the conducting path for electrical current for dynodes.

The electrically resistive layer such as of semi-conducting Al_2O_3 with a suitable activator such as Mo or of materials described above and having electrical resistance not lower than 10^7 ohm and not higher than 10^{11} ohm, in a modification of my invention, instead of being a base for the electron emissive layer 20, may replace it and serve to provide electron multiplication.

The glass forming the walls of the tunnels 6 may be treated so that the surface facing the lumen of said tunnels acquires good secondary electron emitting properties. In such case the construction of the electron guide and multiplier 5 and its modifications may be simplified by the use of tubes of semi-conducting glass described above and treated so that their surface facing the lumen is a good secondary electron emitter. This construction permits the elimination of a separate electron emissive coating such as 7c or 20. In this construction the tunnels 6 may be at an angle to the photocathode or the photocathode at an angle to the tunnels, or the long axes of tunnels 6 may be normal to the photocathode.

The operation of the modification of my invention using secondary electron emissive layer 20 is shown in

FIGURE 4. The photoelectrons entering the apertures 42 are directed into said apertures at an angle so that they will impinge on the walls of said tunnels 6 coated with layer 20. In this construction apertures 42 are slanted at an angle of 45-55° and tunnels 6b in the guide 5 are straight or at an angle in relation to the photocathode 2. In some cases in order to provide the obliquity for the entering photoelectrons, instead of the tunnels, the photocathode 2 may be mounted at the angle. In such a case the tunnels will be normal in relation to the end-wall of the tube. The angle at which photoelectrons enter will depend on the size of apertures and their spacing from the photocathode. The photoelectrons must have only a few hundred volt velocity to produce secondary electron emission greater than unity from the layer 20. The low accelerating voltage in front of the photocathode 2 creates the problem of resolution. As was explained above, my device is characterized by the absence of electron-optical focusing means. The photoelectrons leaving the photocathodes have a range of velocities 0.5 volt-10 volts according to the wave-length of radiation used. The use of 300 to 1,000 volt accelerating potential requires a much closer spacing of the photocathode 2 to the end-face of the guide 5 than devices in which the accelerating potential is a few thousand volts. It was also found that the use of the low accelerating voltage required that the conducting layer 7 be of perforated type such as layer 7b or a perforated member 43 because electrons of a low velocity will not be able to penetrate continuous layer 7.

The inside walls of the tunnels 6 should have a progressively higher potential along their length in order to cause repeated impingement of secondary electrons on the layer 20 while they are traveling to the exit apertures. It was found that the best way to provide progressively higher potential for the walls of the tunnels 6 is to divide the electron guide 5 into plural segments and to interpose between said segments apertured electrically conducting members 43 or apertured layer 7b or conducting rings which can be connected to various electrical potentials required. The conducting layer 7a or semiconducting layer 7c which are on each tunnel are connected to said apertured electrically conducting members. This construction affords a simple and practical solution of supplying progressively higher potential to all tunnels 6 in spite of the fact that we may use 200,000 tunnels or more in one electron guide 5.

I also found that devices of the prior art failed because of impossibility of obtaining an exact registry of the apertures of the end-face of one electron guide 5 or one segment of the electron guide with the apertures of the next electron guide, when many guides are mounted in the tube separately and spaced apart. I found that the best registry was obtained when the electron guide 5 described above was cut into plural segments to produce plural guides and the conducting apertured member 43 was inserted between the segments of said guide in a proper spacing from them and then all parts were fixed into one rigid unit, either mechanically or chemically or by heating. In some cases the conducting apertured members are mounted only on end-faces of the segments of the electron guide and are not between them in a spaced position.

The registry of apertures of successive guides I found to be the main problem for good definition of images. The best method to accomplish a good registry is as follows. An electron guide of one of types described above is mounted on a support which has a few compartments which can be moved apart in one plane only. The electron guide 5 is cut to provide two or more smaller electron guides. The movable parts of the support are moved apart to separate these segments of the electron guide. This provides the space for the mounting of the electronically conducting member 43 such as was described above. At the same time it prevents displacement

of the segments of the electron guide in relation to each other in any other plane. The electrically conducting members 43 are mounted either on the end-face of the segments of the electron guide, or are mounted between the end-faces of said segments. Next the movable parts of the support are moved back. This brings the segments of the electron guide into a close spacing to each other. In some cases an insulating spacer in the form of mica ring may be interposed between two end-faces of the adjacent segments of the electron guide. This will be useful when the apertured conducting members 43 or 7b are mounted between the end faces of the segments of the electron guides. Next the segments of the electron guide with the electrically conducting members 43 are fixed into one rigid unit. In this way a perfect registry of apertures of plurality of electron guides is obtained, which could not be accomplished in the prior art. The above described units comprising plurality of electron guides can be mounted in the vacuum tube without any damage to the registry of the apertures.

The plural segments can be united either by chemical means such as by a plastic compatible with vacuum tube processing such as silicones, fluorocarbons or polyethylenes. The segments can be also joined in one unit with mechanical means, or by the embedding material or by heating and fusing them.

It was found that a part of the photoelectrons does not enter into apertures 42 but strikes instead the solid parts of the guide 5. As the photoelectrons have velocity at which secondary electron emission is higher than unity a positive charge will develop around the apertures 42. I found that this charge reduces considerably the sensitivity of my device. This charge may be removed by mounting on the end-face of the guide 5 a perforated electrically conducting member 43 in such a manner that its apertures overlie the apertures 42 of the guide. Also perforated layer 7b may be used for this purpose. The member 43 of layer 7b are connected to a suitable source of potential and will be able therefore to remove the space charge. It was found that a continuous electrically conducting layer 7 could not be used in this device because the velocity of electron was not sufficient to penetrate through it. The electrons make the exit through the apertures at the end of the electron guide 5. They are accelerated to a high velocity and strike the image reproducing screen 8 through the layer 9. It should be understood that the multiplied electron beam after its exit from the guide 5 may be also used in combination with other devices such as targets of television tubes, storage tubes, and other vacuum tubes.

My construction will therefore produce a device which in spite of its small size is capable of a high image resolution. In addition my device will be very rugged mechanically. In addition my device will reduce the field emission in the vacuum tubes arising from the spreading of caesium vapors.

In another modification of my invention using secondary electron emission for intensification of the images the secondary electron emissive layer 20a is used on the end-face of the guide 5 as it is shown in FIGURE 5. It is preferable to deposit first layer 20a whether it be in the form of a continuous layer or in the form of a discontinuous layer and then to mount on it electrically conducting member 7 or 43 which are transmitting to electrons as shown in FIGURE 5. In some cases the sequence of the layers 20a and of the member 43 may be reversed and the members 43 is the first one to be mounted on the end-face of the guide. The secondary electron emissive layer 20a in this embodiment of invention may be deposited as a continuous layer or as a discontinuous layer which covers essentially only the apertures 42 and the edges around them. It should be understood that in cases in which the fragility of this device is not critical the layer 20a and the member 43 supporting it may be mounted spaced apart from the end-

face of the guide 5E. They must be however very closely spaced in relation to said end-face so that the secondary electrons will enter the apertures 42 without causing loss of resolution. The spacing smaller than 0.1 cm. will be necessary for a good resolution.

The secondary electron emissive members 20a are as thin as 50-250 angstroms so that they will emit secondary electrons in forward direction when impinged by primary electrons of sufficient velocity which may be a few kv. The secondary electron emissive member 20a may be of a conducting material such as copper, beryllium or nickel and they may be connected directly to the source of potential. The same is true about members 20a of semi-conducting materials such as caesium-antimony. If however, the secondary electron emissive material is of dielectric type such as fluorides of calcium or magnesium aluminum oxide, or alkali halides, such as KCl, a conducting layer continuous or apertured should be provided as the base for said electron emissive member 20a. It was found that the use of dielectric type of secondary electron emissive member gives superior results to the devices which use a conducting type of secondary electron emitter.

It was found that in the device described above serious difficulties arise because of the development of space charges. The velocity of photoelectrons for the best operation of the layer 20a should be a few kv. The photoelectrons of this energy striking the solid parts of the electron guide 5 will cause secondary electron emission smaller than unity. As a result a negative charge will develop and the solid parts of the guide 5 around the apertures 42 and will cause various complications in the operation of the device. It was found that this negative charge may be removed by using a continuous type of electrically conducting layer 7 which is connected to a suitable source of potential, in preference to the use of the perforated layer 7b or of the member 43.

The guide 5E in this embodiment of invention has tunnels 6 normal to the photocathode 2, the tunnels 6 have no coating 20 of secondary electron emissive material or of a photoelectron material, as it was described above and shown in FIGURE 1.

It should be understood that the guide 5E may comprise a plurality of short guides, combined in one unit by mechanical means, chemical means, or by heating. Each of short guides is provided with the conducting layers 7, 7b or 43, and has the secondary electron emissive layer 20a on one or both end faces.

It should be understood that the guide 5 may be sliced into many separate segments, and the secondary electron emissive screens described above may be interposed between the segments of the guide. Next all these parts may be combined in one unit, either mechanically or chemically or by heating. In this way cascade intensification of the electron beam by electron multiplication is obtained without any loss of resolution in spite of the absence of electron-optical focusing devices.

It should be understood that the segments of the electron guide 5 provided on end-faces with the layer 20a should be spaced apart to provide sufficient separation for the use of a high accelerating voltage applied in this device. This spacing should preferably not exceed 0.5 cm. to preserve a good definition.

The rest of the operation of the vacuum tube 1B is the same as of the vacuum tube 1. The great advantage of this novel construction resides in ruggedness of this device.

It should be understood that the novel electron guide 5E may be used also in various vacuum tubes such as television camera tubes, storage tubes, kinescopes etc.

In the devices of the prior art the mesh screens coated with secondary electron emissive layer were necessarily very fragile, because of their thinness. In my device the layer 20a and member 43 or 7 are being deposited on the end-face of the guide have mechanical strength

which allows the use in all operating conditions. Another novelty of my device resides in the elimination of electron-optical focusing devices and without loss of resolution.

In some cases the end-walls of vacuum tube 1 or 1A or 1B should be made of fiber-optic plates 12 and 12a as shown in FIGURE 3. It should be understood that this construction applies to all vacuum tubes described in this disclosure. The fiber-optic plates comprise a plurality of light conducting fibers. Each of said fibers consists of a core of material having a high index of refraction such as suitable glass e.g. flint glass, or quartz or arsenic trisulfide or plastics such as acrylic plastics such as Lucite or polystyrenes.

The light conducting fibers should be polished on their external surface very exactly. Each of them must also be coated with a very thin light opaque layer to prevent spreading of light from one fiber to another. I found that without said light-impervious coating, the image will be destroyed by leakage of light from one fiber to another. The light opaque layer should have a lower index of refraction than the light conducting fiber itself. Such a coating may have a thickness of only a few microns. The light opaque coating may be of materials such as a suitable glass or plastic. In some cases it is preferable to use glass or ceramics which will tolerate a high temperature such as of at least 600° C.

Especially glass or plastic of a lower index of refraction than the fibers and containing aluminum or chromium diffused into them are suitable materials for the coating.

In another modification the light opaque layer such as of chromium or aluminum is deposited on the outside of the coating which in such a case may be of a transparent glass or plastic.

All said fibers are glued together with silicones or are fused together by heating them to form a vacuum tight unit. In the use of such fiber-optic plates, care must be exercised to prevent the chemical interaction between the photocathode 2 and the fiber-optic end-wall 12 or 12a.

I discovered that the contact of the end-face 12 or 12a with the photocathode 2 of alkali-antimony type caused an unexpected deterioration of said photocathode. I believe that this effect is due to the presence of boric oxide or lead oxide which are common ingredients in glasses which have a high refraction index. It was found that the best way to prevent this poisoning of the photoemissive photocathode was to provide a thin light transparent member 13 between the end-wall of the tube and the photoemissive layer as shown in FIGURE 3. The light transparent separating layer 13 may be of Al_2O_3 , fluorides, MgO or silicon oxide and it may be of the thickness of a few millimicrons. It is important that layer 13 of Al_2O_3 or other layer used should be of continuous, non-porous type to prevent exchange of ions through said layer. Also same results may be obtained by using a conducting light transparent layer such as of iridium, palladium, or tungsten of similar thickness. In some cases for the best results we may use a combination of a dielectric layer 13 such as of Al_2O_3 layer with a light transparent conducting layer.

I also found that the end-face 12 or 12a must be very smooth to prevent non-uniformity of the photoemissive layer or of photoconductive layer which are deposited thereon. Otherwise false potential gradients will be produced which will effect the definition of the image.

Another important feature of the construction of my device is the provision for protecting the vacuum of the tubes 1A or 1C.

It was also found that the caesium of the photocathode 2 causes discoloration of the fiber-optic plates 12 or 12a, especially if they contain lead. The protecting layer 13 will prevent this complication.

The fibers of the fiber-plates 12 or 12a when subject to the ionizing radiations, were found to discolor which caused losses of transmitted light. The addition of cerium to the glass used for making fibers prevented this complication.

As the fibers have a high index of refraction and alkali-antimony photocathode has a still higher index of refraction it is advisable to interpose between the end-face 12 or 12a and the photocathode 2 a light transparent layer of the thickness of the order of odd number of quarters of wavelength of the light conducted by such fibers and having an index of refraction $n = \sqrt{n_1 n_2}$. In this equation n_1 is the index of refraction of fibers and n_2 is the index of refraction of alkali-antimony photocathode. This layer 13a may also serve as a protecting layer 13 if it is non-porous.

Another embodiment of the device for intensification of images, is shown in FIGURE 6. Two or more vacuum tubes 1, 1A or 1B and 1C provided with fiber-optic end-walls are brought into apposition to each other and are cemented together. The luminescent image from the screen 8 is transferred by the fiber-optic end-wall 12A and 12 to the photocathode 2 of the next tube without a marked loss of resolution.

A modification of this construction is shown in FIGURE 6a. Two vacuum tubes 1A are connected by means of a bundle of fibers 18 attached to the end-walls 12A and 12. The bundle of coated fibers which were described above serves to conduct images by internal reflection of light. The bundle 18 may be flexible or may be rigid. The bundle 18 may be attached to the end-walls 12 and 12A by any mechanical means or may be separated from the end-walls of the tube. In the latter case, an optical system must be interposed between the end-faces of the bundle and the end-walls of the tube.

Another embodiment of my invention is shown in FIGURE 7. The tube 21 is provided with composite screens or intensifying "sandwiches" 22, which comprise the following layers; a light reflecting electron transparent layer 23, such as of aluminum or titanium, a luminescent layer 24 such as of zinc cadmium sulphide or zinc silver sulphide, a light transparent separating layer 25 which may be of mica, glass, a suitable plastic such as silicone, or polyester, alone or in combination with a layer of aluminum oxide, silicon monoxide or other silicon compounds and of the photoemissive layer 26 which may be of any materials described above for the photoemissive layer 2. These composite screens are described in detail in my U.S. Patents 2,555,423, 2,593,925 and 2,690,516. The intensifying screens are deposited on the end-faces of the guide 5. They may be also mounted in apposition to the end-face of the guide 5 and will then form a separate unit. In such a case, they will be supported by the light transparent separating layer, which in this modification will be of glass or mica or of a mesh screen covered with a plastic and Al_2O_3 or SiO . It should be understood that the intensifying screen 22 may be also mounted in separation from the end-faces of the guide 5. In such a case, the distance of separation will be governed by the same rules as described above.

In case the screen 22 is deposited on the end-face of the guide, the separating light transparent layer 25 may be preferably of silicone or polyester in combination with a thin layer of aluminum oxide, magnesium oxide or silicon monoxide or other silicon compounds.

The contact of the photoemissive layer 26 with the end-face of the guide 5 may cause chemical poisoning of the layer 26 and discoloration of the glass. In such case the perforated layer of materials described above for the protecting layer 13 must be interposed between the layer 26 and the end-face of the guide 5. The perforated protecting layer 13b must be mounted in such a manner that its apertures will coincide with the apertures 42.

The photoelectrons from the photocathode 2 impinging on the composite screen 22 will give 10-20 more of

new photoelectrons according to the accelerating voltage used.

It should be understood that a few guides 5 provided with the intensifying screens 22 may be mounted in the same tube for a cascade intensification of images. It should be understood that the rest of the operation of the vacuum tube 21 is the same as was described above.

A modification of the invention is shown in FIGURE 8. In this construction, the composite screen 22 is disposed between two guides 5. The composite screen 22 may be separated from the end-face of the guide 5 in which case, the light transparent separation layer 25 of glass or mica or of a mesh screen covered by a plastic and Al_2O_3 or SiO will serve as a support. The composite screen 22 may be brought in contact with the end-faces of one or both guides 5. The composite screen 22 may be deposited on the end-face of guides 5 as one unit. It is an important feature of my invention that some layers of the composite screen 22, may be deposited on the end-face of one guide 5 and other layers of the screen 22, may be deposited on the end-face of the next guide, and then both guides may be brought into apposition together. A good combination is to deposit the layers 23, 24 and 25 on one guide 5 and the layer 26 on the end-face of the other guide 5. Many variations of such splitting of the composite screen 22, are feasible and it should be understood that all of them come into the scope of my invention.

It should be also understood that secondary electron emissive layers 20a can be used in combination with the composite screens 22 as shown in FIGURE 8.

It should be also understood that composite screens 22 may be used on both sides of each guide 5, either in apposition or in deposition or in separation from said guide as it was described above.

If the screen 22 is brought into apposition with the guide 5 or if the photoemissive layer 26 is in contact with the end-face of the guide 5 it is important to prevent chemical interaction between the photoemissive material and the materials present in the end-face of the guide 5. This can be accomplished by the depositing on the solid parts 44 of the end-face of the guide a very thin protecting layer of a plastic, such as silicone or a polyester, or of a glass such as lime glass or borosilicate glass or aluminum oxide or silicon oxide, or a fluoride or a combination of a few of these materials in the form of superimposed layers of aforesaid materials. These protecting layers 13b should be preferably apertured and deposited so as not to obstruct the apertures 42 of the guide. The conducting perforated member 7a or 43 may be deposited on either side of the protecting layers and will be connected to an external source of electrical potential.

It should be understood that the guide 5 may be sliced into many separate segments, and the screens 22 may be interposed between the segments of the guide. Next all these parts may be combined in one unit, either mechanically or chemically or by heating. This construction will provide cascade intensification of the images. The protection of the photoemissive layer 26 from interaction with the materials of the end-face of the guide 5 will be the same as was described above.

It should be understood the composite screens 22 may be used in combination with all types of the electron guide described in this specification and may serve in all types of vacuum tubes.

In case the intensifying screen 22 is not supported by the guide 5, the construction described above, may be preferably modified in the way shown in FIGURE 9 and FIGURE 10. The supporting layer 25 in this construction is replaced by a short bundle of light conducting fibers 27 which were described above. Each fiber comprises a core of transparent glass or plastic 27a of a material, having a high index of refraction and a coating 27b of a material having a lower index of refraction

than said core 27a such as of a glass or plastic or of a metal such as aluminum. The coating 27b is light opaque to prevent the escape of light and loss of contrast as was explained above. Sometimes an additional layer 27c of a light opaque metal such as of aluminum is deposited on the layer 27b or a metal such as Al or Cr is diffused into the coating 27b. All fibers are fused together at their end only or along their entire length by heating them or by glueing them into one unit. The other layers of the composite screen such as layers 23, 24 and 26 are mounted on the respective end-faces of the fiber bundle 27. This construction offers a much greater ruggedness than the previously described screens 22 and without loss of resolution.

The photoemissive layer 26 has to be protected from the interaction with the materials in the bundle of fibers 27 in the same way as was explained above, by layer 13.

Another way to make the composite screen 22 rugged without sacrificing resolution or contrast of images is shown in FIGURE 10a. In this construction, the supporting layer 25 of the screen 22, is replaced by a wide mesh screen 28 which is coated on each side or on one side only with a layer of silicone 28a or of polyester or of other light transparent heat resistant, low-vapor plastic. On one side, of the layer 28a, there is deposited in addition, a light transparent, very thin layer of aluminum oxide, magnesium oxide or silicon oxide or other silicon compounds. It should be understood that the construction of the composite screen 22 described in FIGURE 10 or 10a applies to all embodiments of my invention in which such a screen is used.

Another great advantage of my invention resides in the possibility of preparing the luminescent screen 8 and the photoemissive layer 2 in a close spacing to each other, without the danger of contamination of the luminescent material of the screen 8 by caesium or other vapors which has not been possible in the prior art. In my device, the photoemissive layer 2 and screen 8 are separated by the guide 5 which prevents the spreading of Cs to the screen 8. If a perforated type of layer 7 is used, the apertures of channels 6 may be closed by a layer of nitrocellulose or of other material which will be removed by the baking processing of the vacuum tube.

When a plurality of guides 5 with intensifying screens 22 or 7a-20a are used, it may be advantageous to process the guide 5 with the screens attached to it outside of the vacuum tube in a demountable extension of said tube. After completion, the guide 5 with screens 22 is introduced into the final vacuum tube and is mounted thereby mechanical means.

The sensitivity of my imaging devices described above may be further increased by using a novel optical objective for focusing the image on the photocathode 2 which is a combination of a lens 31 with a tapered light conducting fiber bundle 32, instead of using the lens alone, as shown in FIGURE 11. The fiber bundle 32 may be attached to the fiber-optic end-wall 12 of the vacuum tubes carrying the photocathode 2, which were described above, by any mechanical means. The fiber bundle 32 comprises a plurality of tapered fibers 27d for the demagnifying of the image produced by the lens.

Each fiber comprises a core of transparent glass or plastic 27a of a material, having a high index of refraction and a coating 27b and of a lower index of refraction than said core 27a of materials such as of a glass or plastic or of a metal such as aluminum. In some cases it is preferable to use glass or ceramics which will tolerate a high temperature such as at least 600° C. In some cases the coating 27b is preferably light opaque to prevent the escape of light and loss of contrast, or an additional layer 27c of a light opaque metal such as of aluminum is deposited on the layer 27b or a metal such as Al or Cr is diffused into the coating 27b to render it light opaque as was described above. All fibers are fixed together at their ends only or along their entire length by

heating them or by glueing them chemically into one unit. If the fiber bundle should be flexible, then only the ends of the bundle should be fixed together. If a rigid bundle is wanted, then the fibers are fixed together along their entire length.

In modification of this invention, the fiber bundle 32 may enter the vacuum tube 1F and form a part of its end-wall which in this case, does not have to be made of fiber-optic plate, but may be of the usual glass or metal, construction. The fiber bundle 32 will therefore form a part of the end-wall of the tube or it may replace the whole end-wall. The photocathode 2 is then deposited on the end-face of the bundle 32. As it was described above, precautions must be taken to prevent chemical interaction between the fibers of the bundle and the photoemissive layer 2. A very thin light transparent separating layer 13 should therefore be interposed between the end-face of the bundle 32 and the photoemissive layer 2. The layer 13 may be of aluminum oxide, magnesium oxide or other silicon compounds.

Another modification of my invention which is shown in FIGURE 13 will be of a great importance for television pick-up tubes which have an image section such as image orthicon or image vidicon. My device will permit elimination of electrostatic or electromagnetic focusing devices in the image section used in the present television tubes. In this construction, the photoelectrons from the photocathode 2 of the image orthicon, or other television pick-up tube, are guided to the target 30 by the guide 5. The electrons transmitted through the guide reach the target 30 which is closely spaced to said guide without loss of resolution.

It was also found that the perforated mesh screen used to collect secondary electrons degrades resolution in television camera tubes. In my invention it may be replaced by a continuous conducting layer 7 which is mounted on or adjacent to the end-face of the guide 5 close to the target 30 instead of a mesh screen. The electrons from the photocathode 2 focused by the guide 5 have velocity high enough to pass through the layer 7 which is made very thin to be transparent to electrons, and to impinge on target 30. The secondary electrons from the target 30 are collected by the layer 7.

My invention can be also used for images of invisible radiations such as X-rays, infra-red, or images of atomic particles such as neutrons or electrons or for images formed by supersonic waves. In such case, the photocathode 2 must be modified, to make it responsive to the radiation used for image forming purposes. The photocathode for X-rays or atomic images were described in my Patents 2,555,423 and 2,690,516. The photocathodes described in the above patents, may be modified by using a fiber-optic bundle 27 instead of a light transparent separating layer, as it is shown in FIGURE 9, or by a screen shown in FIGURE 10a.

The photocathode for supersonic images will comprise a piezoelectric plate 35 covered by a continuous or mosaic layer 34 of a photoemissive material such as was described above for the layer 2, as shown in FIGURE 13c. The layer 34 is irradiated uniformly by a source of light 65 causing emission of a beam of photoelectrons. The supersonic image is converted by piezoelectric layer 35 into a pattern of potentials corresponding to said image. This voltaic or charge pattern modulates the emission of photoelectrons from the layer 34 or of secondary electrons from the layer 36. The photoelectron beam has therefore the pattern of the original supersonic image. The photoelectron beam enters the guide 5 and remains focused by said guide. It may be also intensified if the guide has secondary electron emissive layer 20a or 20 or screen 22, as was described above. The intensified electron beam may be converted into a visible image as was explained above illustrated in FIGURE 1 or it may be converted into video signals as it was illustrated in FIGURE 13.

In another modification 68 shown in FIG. 13a the piezoelectric plate 35 is covered by a layer of a secondary electron emissive material 36 of one of materials described above for the layer 20 or 20a. The electron guide 5 in this modification has a hollow tunnel 37 through which the electron beam from the electron gun 40 may pass and impinge on layer 36 in a scanning pattern to produce a secondary electron emission from it. The deflecting means 53 will serve to produce a scanning motion of the electron beam. The high velocity electron beam from the electron gun 40 causes secondary electron emission from the layer 36. This electron emission is modulated by the voltaic pattern in the plate 35. The secondary electrons enter the guide 5 and are intensified there by secondary electron emission, as it was described above and shown in FIG. 1e or FIG. 4. The multiplied electrons may be converted into video signals, as it is known in the television art.

It was found that the device 67 shown in FIG. 13c failed when a standard source of light was used. It was found that devices 67 or 69 could operate well only if the source 65 emitted only red or infrared light. In addition the source of light 65 should be preferably monochromatic or should emit in a narrow range of wavelengths. The use of standard source of light causes emission of photoelectrons ranging from 0.1 volt to 5 volts velocity. It was found that such range of photoelectrons could not be modulated with piezoelectric voltages on the plate 35.

The piezoelectric layer 35 may be of a continuous type or of a discontinuous mosaic type in all devices described.

The supersonic image devices shown in FIGS. 13a, 13b, and 13c may be further improved by combining the piezoelectric layer 35 with a member 70 which intensifies supersonic waves. The member 70 may be in the form of a thin layer of a semi-conducting material such as CdS or ZnO. Especially CdS of a thickness of a few microns exhibits strong amplification of supersonic waves. Addition of activators such as Cu either by diffusion of Cu into CdS or by evaporation of Cu with CdS increases this amplification effect further. The amplifying layer 70 should be plated with conducting layers 72 and 73 such as of indium or tin oxide which are connected to a source of electrical potential to provide a uniform field through said layer 70. The conducting layer 72 preferably should be light transparent. It was found that irradiation of layer 70 with light through the conducting layer 72 improves supersonic amplification. The supersonic amplifying layer 70 is responsive to longitudinal and to transverse supersonic waves and responds to a very wide range of frequencies of supersonic waves. The intensified supersonic waves emitted by layer 70 impinge on the piezoelectric layer 35 through the conducting layer 73 and produce potential or charge pattern corresponding to the original supersonic image.

In a modification of my invention the supersonic amplifying layer 70 is made preferably in the form of a mosaic 71 formed by a plurality of islands of CdS, ZnO or other suitable material and is mounted on the piezoelectric plate 35 as shown in FIG. 13a. Such a mosaic may be produced by evaporating the amplifying material through a mask or a mesh screen on a piezoelectric plate 35 which is first coated with a conducting layer 73. After evaporation of the mosaic 71, electrically conducting layer 72 is evaporated to provide the second electrode.

The piezoelectric layer 35 may be a self-supporting layer, and may serve as a support for the other layers and may also form the endwall of the vacuum tube.

It was found that difficult bonding problems arise in bonding the piezoelectric layer 35 to the glass of the envelope of the vacuum tube to make it the endwall of the tube. The use of indium seal or of epoxy seal is not efficient when piezoelectric plates of a large diameter have to be cemented, as it is required in some applications. It was found that the best solution is to use

a vacuum tube envelope of a ceramic. The piezoelectric plates of a large diameter may be well joined to said ceramic envelope by brazing. In some cases the tube envelope of a metal is preferable and it was found that piezoelectric plate 35 of quartz could be well bonded with the metallic envelope. Another solution of this problem is to mount the piezoelectric layer 35 on the inside surface of the endwall of the vacuum tube.

In some cases the conducting layer 72 or 73 may be eliminated. This modification applies to all embodiments of my invention.

The piezoelectric layer 35 may be of a continuous type or of a mosaic type. It may be made of titanates, quartz, niobates or other piezoelectric materials. The layer 35 may have a high resistivity such as 10^{15} ohm-cm., or it may be of a semiconducting material, having resistance of 10^7 ohm-cm. to 10^{11} ohm-cm. The titanates or niobates can be prepared in a semi-conductive form by doping them with suitable agents. The mosaic type of layer 35 may be constructed by assembling a plurality of small crystals or by evaporating a polycrystalline layer or by mechanically grooving a large crystal into many small units.

Supersonic waves can be conducted by the fiber bundle 27 described above. By using as a source of image forming radiation piezoelectric or magnetostrictive generators of supersonic waves and conducting said waves to the examined part, we may produce supersonic images. Piezoelectric generators may be in the form of oscillating crystals of quartz, titanium compounds, such as titanates, Rochelle salts and other similar materials. The supersonic waves may be directed to the examined part by supersonic lenses or preferably by means of the fiber bundle 27. The supersonic waves reflected or transmitted by the examined part may be directed to the supersonic image sensitive member by the same fiber bundle or preferably by an additional fiber bundle. The supersonic sensitive member may have the form of piezoelectric elements, such as were described above for the supersonic generator, but smaller in size. In another embodiment of invention, the supersonic image sensitive member is a vacuum tube provided with a piezoelectric continuous or mosaic electrode 35; said piezoelectric screen or electrode receives the supersonic image of the examined part and converts said image into an electrical pattern of potentials or charges which correspond to said supersonic image. Such a vacuum tube is provided with a source of electron beam, such as electron gun for irradiation of said piezoelectric screen or electrode. The electron beam scans said piezoelectric screen or target, is modulated by the electrical pattern present on said screen or electrode and the returning modulated electron beam is converted into electrical signals in the manner well known in the television art.

In some cases the photoemissive layer 34 or secondary electron emissive layer 36 may be mounted in a closed spacing to the piezoelectric layer 35 as a separate unit. In such case the layer 34 or 36 must have a perforated support such as member 43 described above. The support for the layer 36 should be preferably of conducting material but in some cases dielectric material may be also used. The unit 43-36 or the unit 43-34 may be in contact with the layer 35 or may be mounted at a very small distance from the layer 35 such as one or a few microns at most. The electrons emitted by the layer 34 or 36 will enter the novel guide 5 for their focusing and in some cases for their further intensification as was described above.

In another modification 69 of this invention the photoemissive layer 34 or secondary electron emissive layer 36 are mounted on the end-face of the electron guide 5. The electron guide 5 is mounted in a distance of one or a few microns from the target 35, as shown in FIGURE 13b.

My device will be useful for construction of a novel electron gun which will offer an improvement of resolu-

tion of the electron beam. It is well known in the art that it is difficult to produce an electron beam of a small diameter without use of strong electrical or electromagnetic fields. My electron guide 5 and its modifications will permit the producing of the electron beam as small as of ten microns diameter or less without focusing fields. This construction is shown in FIGURE 14. The electron beam emerging from the source of electrons 40 enters into a closely spaced guide 5 having the apertures 42 of the size of five to ten microns, or of any other size desired and which is mounted in the vacuum tube 1D.

The guide 5 has essentially the same construction as was described above and all modifications of the guide 5 apply for the use in the novel electron gun 62 construction. In case a scanning electron beam is wanted the deflecting members 53 will direct the electron beam sequentially into various apertures 42 of the guide 5 to produce a scanning pattern. The deflecting means may also be mounted after the guide 5 instead of in front of it and will deflect the electrons after they were transmitted through the guide 5. The electrons traveling through the tunnels 6 of the guide remain focused therein. As the electron beam emerges from the apertures on the exit side of the guide 5 or 5A it has the same spot size it had at its entrance into the guide. It should be understood that the guide 5A may have tapered tunnels as it was described above, which may be of convergent form, in which case the electron beam will be demagnified upon its exit. In other cases, the tunnels may be of divergent form in which case the electron beam will be magnified upon its exit. It should be understood that apertures 42 may have a bevelled shape or other shapes.

The problem of prevention of space charge development will be solved in the same way as was described above.

In order to obtain the best definition of the electron beam the electrons which travel through the tunnels 6 of the guide 5A must be prevented from striking the walls of said tunnels. This can be accomplished by providing the walls of said tunnels which face the lumen with a conducting or semi-conducting coating 7a. The conducting coating may be of aluminum or chromium. The semi-conducting coating may be of tin oxide or of titanium oxide. The coating 7a may be connected to the perforated conducting member 43 or 7b which again may be connected to an outside source of an electrical potential. As all tunnels 6 are in contact with the member 43, walls of said tunnels will have an electrical potential which will repel electrons. In this modification the tunnels 6 should be normal to the electron beam and the apertures 42 symmetrical in shape.

In some cases, the second perforated member 43 is mounted on the opposite end of the guide 5 or 5A. In this construction the member 43a may be connected to the external source of potential to provide acceleration for electrons.

In addition my electron gun can bring about intensification of the electron beam produced by the electron gun 40 without increasing the noise of the electron beam, which is of the utmost importance for many devices. The intensification of the electron beam from source 40 such as standard electron or matrix gun may be accomplished by all constructions described above, for example by depositing a very thin secondary electron emissive layer 20a on the end-face of the guide 5A as was described above and illustrated in FIGURE 5. The electron emissive layer 20a is deposited on the endface of the guide. On layer 20a is mounted electrically conducting layer 7 or 7a or 43 thin as to be transparent to electrons, and connected to a suitable source of potential. The layer 20a may be continuous, but preferably it should be discontinuous. In the discontinuous construction it may overlie the apertures 42 of tunnels 6 but be absent from the solid parts of the guide 5 except around the edges of apertures. In some cases the electrically conducting layer 7b

which provides potential for the secondary electron emissive layer 20a is deposited not only over the apertures of the guide 5, but as a continuous layer 7 extending over the solid parts of the endface of the guide and over the apertures of the guide as well. This construction will be important for prevention of the accumulation of the space charge which may be very detrimental for the operation of the novel electron gun 62.

If the secondary electron emissive layer 20a is used on the end-face of the guide 5, it is preferable to deposit first said layer 20a whether it be in the form of a continuous layer or in the form of a discontinuous layer on the end-face of the guide and then to mount the member 43 or 7, as shown in FIGURE 5 or FIGURE 14. In some cases the sequence of the layer 20a and the member 43 may be reversed and the member 43 is the first one to be mounted on the end-face of the guide. It should be understood that in cases in which the fragility of this device is not very critical the layer 20a and the member 43 may be mounted as one unit spaced apart from the end-face of the guide 5 or 5A. They must be however very closely spaced in relation to said end-face so that the secondary electrons will enter the apertures 42 without causing loss of resolution.

Further intensification of the electron beam may be accomplished by using a few guides 5, 5A or 5D each of them being provided with a secondary electron emissive screen comprising layers 43 and 20a. All such guides are combined in one unit by mechanical means, chemical means, or by heating. In this way a cascade intensification will be obtained. It should be understood that all modifications of the guide 5 may be used for such a cascade or tandem construction.

An additional intensification of the electron beam from the electron gun may be accomplished by depositing the secondary electron emissive layer 20 on the inside walls of the tunnels 6a, as it was explained above. The electron beam from the electron gun in such case is directed into apertures of the guide normally or at an angle, the size of which will depend on the spacing between the electron gun 40 and the size of apertures 42. The oblique entrance of the electron beam into tunnels 6a causes impingement of the electrons on walls of the tunnels 6 and produces thereby secondary electron emission from the layer 20. The materials for the layer 20 were described above. The layer 20 is deposited on the electrically conducting layer or semi-conducting layer or resistive layer 7c as it was explained above, and which is connected to the source of electrical potential. The secondary electrons emitted from the layer 20 strike the next part of the wall of the tunnels 6a. In this way, the intensification process is repeated until the electrons emerge from the tunnels 6a. As the electrons emerge from the guide, the electron beam size remains limited to the size of the diameter of the aperture, but it is greatly intensified, without introduction of any additional noise.

It should be understood that my device will be useful for all sources of electron beams whether the electron beam is produced by a hot filament or by a cold emission or by a field emission. It should be understood therefore, that the definition "electron gun" used in this specification and in the claims embraces all such sources of the electron beam.

It should be also understood that all modifications of the electron guide 5 such as 5A, 5B, 5C or 5D described above may be used for the construction of the novel "electron gun."

It should be understood that this novel electron gun may be used for television camera tubes, for kinescopes, for black and white images or for color images, and for storage tubes. It should also be understood that my device will be useful for devices using a broad electron beam such as applied for "reading" in storage tubes or for electron mirror tubes.

My invention will be of great importance for construc-

tion of novel storage tubes such as having electron gun or a photocathode or both. The present storage tube has a very low resolution such as $\frac{1}{2}$ pair lines per millimeter. I found that this low resolution is due to inability of the storage target in these tubes to focus the broad "reading" electron beam into a plurality of electron microbeams small enough to depict image points of a minute size such as it is necessary e.g. for resolution of 10 pair lines per millimeter.

This problem was solved in my device in which the broad electron beam is split into plurality of small electron beams by the novel electron guide. The split electron beam can be as small as 10 microns in diameter and will give the final image of a high resolution which was not possible before.

In conclusion my invention allows the separation of the two functions which were before provided by the storage target of the prior art, such as modulation of the broad electron beam with a stored charge pattern and focusing of said beam.

In this embodiment of invention, shown in FIGURE 15, the electron guide 5B in the vacuum tube 1E has the electrically conducting member 43 or 7b of aluminum or nickel such as was described above, deposited on the end-face of the guide 5B. Next the secondary electron emissive layer 52 of dielectric material such as alkali halides or MgO or Al_2O_3 is deposited on said conducting member 43.

The sequence of the layer 52 and of the member 43 may be reversed in some cases and the layer 52 is deposited on the end-face of the guide 5B first.

The member 43 and layer 52 are deposited on the solid parts 44 of the end-face of the guide 5B in such a manner as not to obstruct the apertures 42.

In operation of this storage device, the photoelectrons from the photocathode 2 or from another source of electron beam which is image modulated such as an electron gun 40 are directed to the end-face of the guide 5B and impinge on the secondary electron emissive layer 52 producing a positive or negative charge image on the end-face of said guide according to the potentials used. The charge image cannot leak away because it is formed on a dielectric layer 52 as shown in FIGURE 15. As a result a stored charge image remains on the end-face of the guide 5B and has the pattern of the original electron image. Next a broad non-modulated electron beam is produced either by irradiation of the photocathode 2 with a uniform source of red or infrared light, or by using an electron gun 40 for this purpose. The broad electron beam as it enters the apertures 42 of the guide 5B will be modulated by the stored charge image, and will have, therefore, imprinted on it the pattern of the original image. The broad electron beam is decelerated before the end-face of the guide by a mesh screen or by conducting rings connected to a suitable source of electrical potential. The broad electron beams after being split into plurality of microbeams by the electron guide 5B is directed onto image reproducing screen and reproduces a visible image. Instead of a luminescent screen 8 other types of screens such as scotophore screens, targets, such as dielectric tape, or photoconductive or semi-conductive targets may be used as well.

It should be understood that the storage unit 43-52 may be mounted in apposition or in a close spacing to the end-face of the guide 5B as a separate unit.

It should be understood that the electron guide 5B used in this embodiment of the invention may be made by any method and may be of any type described in this specification. It should be understood therefore that "reading" electron beam may be intensified by secondary electron multiplication and by cascade use of plurality of electron guides.

In some cases, instead of a storage material 52 of a dielectric type, a semi-conducting material or even a conducting material such as Be, Cu or Ni may be used. Such

conducting storage layer must be deposited as a discontinuous mosaic on the dielectric solid parts 44 of the end-face of the guide 5B and will be able to store the charge pattern because of its dielectric base.

It should be understood that the electron storage-guide unit may be also used in any type of vacuum tubes such as camera television tubes, kinescopes etc. and my invention is not limited to the image type of tube 1E.

It should be understood that all vacuum tubes described above may be operated in a continuous manner, or in a pulsed manner. In the pulsed operation the potential for the acceleration of electrons from the photocathode 2 or electron gun 40 is suspended for a short duration. This time interval may be also used for providing a suitable positive or negative potential to the conducting or semi-conducting coating on the inside walls of tunnels 6 in order to eliminate positive or negative space charge accumulations. The positive potential may be applied to the end-face of the guides 5 to dissipate the negative charges present thereon, or a negative potential may be applied to dissipate positive charges present thereon. It will depend on the type of the vacuum tube and on its operational voltages whether we will have positive or negative space charge.

It should be understood that all types of the electron guide may be used in each embodiment or modification of my invention.

A great improvement of definition and contrast of images was realized in the embodiments of invention shown in FIGURES 15c, 15a, and 15b. In this construction the tunnels 81 of electron guide and multiplier 80 are curved. Without going into theoretical explanation it is sufficient to say that the construction of the electron guide device built of strongly curved or even spiral tunnels in contradistinction to the straight tunnels markedly improved the performance of all my devices both in definition and contrast of images and instability of operation.

It was unexpectedly found that the image will be faithfully reproduced regardless of the curvature or in tortuosity of the tunnels 81 as long as the spatial relationship of all entrance and exit apertures remains the same. It was also found that apertures of entrance into tunnels 6, 80 or 83 and apertures for exit from said tunnels do not have to be coaxial. It means that apertures for exit of electrons may be in a different plane than the entrance apertures and in spite of it the image will be faithfully reproduced, as long as the spatial relationship of all exit apertures is the same as the spatial relationship of all entrance apertures.

Another important finding was that the tunnels 81 between their apertures 81a and 81b may be of different diameter and shape than the apertures themselves without affecting the definition of the images. It was found that the definition of images depends only on the dimensions of apertures and how closely said aperture are spaced to each other and not on the dimensions of tunnels between said apertures.

It was also found that the tunnels may be separated along their course from each other and that the definition of images will not suffer as long as the entrance apertures and the exit apertures of tunnels 81 are spaced as closely to each other as it is possible.

In view of the above findings the curved construction of the electron guide 80 was found to be feasible and compatible with a good definition of images. It should be understood that the curved or spiral construction of the electron guide and multiplier 80 applies to all modifications of my electron guide or multiplier and that it may be used in all devices described herein. The curved construction of the electron guide 80 created a new problem. The electron guide 80 uses 100 to 500 tunnels in each plane, as each tunnel represents one image point. In order to bring this number of curved tubes or other hollow members which form tunnels in apposition together, each successive curved tube must be a little longer than the preceding one. As a result the 100th tube will be consider-

ably longer than the first tube, if the apertures of all tubes in all planes of the electron multiplier **80** should be in one and the same vertical plane, as it is shown in all FIGURES 1 to 14. It was found however that the great differences in length of tunnels **81** cannot be tolerated because they cause great differences in output signals producing thereby incorrect contrast values. The solution of this problem is to equalize the length of all tunnels as shown in FIGURES 15a and 15b. It should be understood that in devices in which the contrast is not important the equalization of length of tunnels may be omitted. The construction based on the equalizing the length of all tunnels results in formation of end-face **82** of the electron guide **80** which has slanted shape, which means that it is inclined at an angle to the long axis of vacuum tube, as it is shown in FIGURE 15a. In some cases it may be preferable to equalize the length on both entrance and exit side of the electron guide **80** as it is shown in FIGURE 15b. The slanted end-face **82** of the electron guide was found to cause geometrical distortion of reproduced images if conventional focusing means were used. This distortion can be improved by using suitable electron-optical lenses. It was found however that a simple solution was to mount the image reproducing screen such as a luminescent screen **8-9** or a target of the television tube also at an angle so that the endface **82** and the image reproducing screen are parallel to each other, as shown in FIG. 15d.

If the image reproducing screen is the target of a television pick-up tube, the scanning electron tube when scanning such slanted targets will cause so called trapezoidal distortion of the image. Suitable focusing electron-optical lenses to correct such distortion are known in the art and do not have to be described in detail.

Another modification of curved electron guide and multiplier **80** is a spiral electron multiplier **83**. The electron multiplier **83** is constructed of spiral tunnels **83a**.

The spiral construction of tunnels is shown in FIGURE 15c. It was found to be compatible with resolution of images provided the entrance aperture **81a** and exit apertures **81b** are spaced in contact or in a closed apposition to each other. The spiral construction requires however a large size vacuum tube as an array of spiral tunnels **83a** occupies a much larger space than array of curved typed tunnels **81**. The equalization of the length of all tunnels is necessary also in this modification of the invention and was described above.

It should be understood that the spiral electron multiplier **83** may have all modifications of electron guide and multipliers described in specification and may be used in all devices described herein.

It should be understood that all image intensifying devices described in this specification whether they are of image tube type or television type or of storage tube type may be modified to make them responsible to invisible radiations of electro-magnetic type such as X-ray, ultra-violet or infrared, or of atomic particles type such as neutrons or protons, or of acoustic type such as supersonic radiation.

FIGURE 16 shows the X-ray sensitive image intensifier **85**. Instead of a light sensitive photocathode **22** I am using a composite photocathode in a form of a screen which comprises a fluorescent or luminescent layer **24** and a photoemissive layer **26**. Such screens were described above. For higher energy X-rays such as gamma rays a photocathode of gold or lead may be used alone or in combination and in apposition with the composite screen **22** described above. In some applications the fluorescent layer may be mounted on the outside surface of the end-wall of the vacuum tube, the photoemissive layer **26** being mounted inside of the vacuum tube. The X-ray image intensifier converts the X-ray image into a fluorescent image. The fluorescent image is next converted into a photoelectron beam corresponding to said image. The photoelectron beam is fed into the electron

multiplier **5** or modifications, **80** or **83**. The multiplied electron beam exiting from the multiplier **80** is projected or focused on the image reproducing screen such as luminescent screen, e.g. **9-8** or on a target of a television pick-up tube such as **30** or on a storage unit such as **40-52**. It was found that the electron multiplier **80** or **83** is very useful for intensification of X-ray images. It was found that besides the intensification of the photoelectron beam emitted from the composite photocathode **22**, it provides also a direct utilization of the X-ray beam which carries the X-ray image. In particular it was found that only 15% of the X-ray beam is absorbed in the composite photocathode **22**. The rest of the X-ray beam passes through said photocathode and strikes the input end-face of the electron guide **80** or **83**. The impingement of the X-ray beam on the secondary electron emissive coating of material on the inside surface of the lumen of the tunnels **81** or **83a** results in conversion of X-ray photons into electrons. The emitted electrons are now multiplied in the electron guide **5**, **80** or **83** as was described above. In order to prevent the loss of definition we must prevent separate fine pencils of the X-ray beam which correspond to separate image points from striking a few tunnels of electron guide instead of being limited to essentially one tunnel only. In order to confine the X-ray beam to proper tunnels, the size of the electron multiplier for the use in diagnostic radiology should not exceed 6 inches in diameter. In addition it was found that the electron multiplier should be spaced in the vacuum tube in a symmetrical position in relationship to the sidewalls of the tube which means that it should be at the same distance from both sidewalls.

In some cases it is necessary to provide electron-optical demagnifying means either of electrostatic or electromagnetic type between the composite photocathode **22** and the electron guide or multiplier **5**, **80** or **83**. This arrangement will permit the use of an electron multiplier smaller than the photocathode which is important in some applications. In addition it will provide an extra intensification of the X-ray image.

In other applications it was necessary to use electron-optical means of magnifying type in order to enlarge the image from the photocathode before projecting it on electron guide or multiplier. This arrangement will permit to preserve the definition of images which is available in the photocathode and which is too high for electron guide or multiplier to reproduce. For example the photocathode may be able to produce an image having definition of 15 pair lines per millimeter. On the other hand the electron multiplier can produce images of only five pair lines per millimeter definition. By using electron-optical magnification by a factor of 3, the image on the endface of the electron multiplier will now have definition instead of 15 only of 5 lines per millimeter and will be therefore resolved well by the electron multiplier. After the passage through the electron multiplier the image may be again demagnified if necessary and the original definition regained.

It should be understood that the use of the electron-optical **82a** demagnifying or magnifying means applies not only to X-ray devices but to all other embodiments of invention as well.

FIGURE 17 shows the neutron sensitive image intensifier **85a**, wherein a neutron reactive layer **86** preferably from the group boron, lithium, gadolinium and uranium or of paraffine is placed on the face of the image tube. The protons or electrons liberated from this layer **86** under the impact of neutron radiation will strike directly or through a thin electron pervious chemically inactive barrier layer, a suitable fluorescent layer **24**, causing it to fluoresce and activate a suitable photoemissive layer **26** through the light transparent barrier layer **25**. In other cases a neutron reactive layer of copper or other gamma emitter such as cadmium **88** will be more advantageous, because of its gamma emission and may be mounted on

the outside surface of the endwall 87 of vacuum tube or may be adjacent to said endwall but spaced apart from said wall 87, as it is shown in FIGURE 18a.

In some cases it may be more desirable to eliminate the fluorescent layer 24 and to cause protons and electrons from the layer 86 to act on electron emissive layer either by apposition or by focusing them with magnetic or electrostatic fields. In some cases the electron emissive layer may be omitted and the beam of the atomic particles from the neutron reactive layer 86 may be focused directly on the electron guide and multiplier 5 or its modifications, 80 or 83.

The fluorescent layer 24 may be also combined with the layer 86 or 88 in one composite layer and may be in this form mounted within the tube or outside of the tube 85a.

The fluorescent layer to be used in the neutron sensitive tube may be of a similar composition as described above in the X-ray sensitive image tube 85, but it has also to be adapted to respond most efficiently to the radiation emitted from neutron sensitive layer by enriching it with proper additional elements. The photo-emissive layer has again to be correlated with spectral emission of fluorescent layer. The other parts of the tube 85a are the same for neutron sensitive image tube and for X-ray sensitive image tube 85.

FIGURE 18 shows infra-red sensitive image intensifier 89. Instead of the photocathode 2 a very thin layer 90 of black gold or platinum is used. The impingement of infrared radiation through a suitable window in the endwall of the vacuum tube 89 such as of sodium chloride, quartz or arsenic sulphide produces in said layer 90 a pattern of different temperatures corresponding to the pattern of said infra-red image. The adjacent photo-emissive layer 26 is irradiated by light from an extraneous source 91. The emission of photoelectrons is modulated by said pattern of temperatures in said layer 90. The emitted photoelectrons are directed into entrance apertures of the electron guide 5 or its modifications, 80 or 83 for multiplication. The rest of the construction of the tube 89 is the same as in any one of modifications described herein.

FIGURE 18a shows another modification of the infra-red sensitive image intensifier. In this construction the layer 90 of gold or platinum is followed by a layer of photoconductive material 92 such as PbS, PbSe, PbTe or Se.

Next follows a very thin chemically inactive barrier 93 such as of MgO, SiO or SiO₂ or TiO₂. On layer 93 is mounted a very thin conducting layer 93a such as of tungsten, platinum or palladium which may be in the form of a continuous layer of a mesh screen. On layer 93a is mounted photoemissive layer 26 which may be in a form of a continuous layer of a mosaic layer. In some cases the photoemissive layer 26 and conducting layer 93a may be mounted spaced apart from the photoconductive layer 92. In such case the barrier layer 93 may be omitted. The infra-red beam causes changes in electrical conductivity of layer 92. The layer 92 is connected to one terminal of a source of electrical power 91a such as battery or to a source of a low frequency electrical current. The other terminal of the electrical source 91a is connected to the conducting apertured member 94 mounted after the photoemissive layer 26 and spaced apart from it. The screen 94 is biased in such a manner that the photoelectrons from the layer 26 cannot pass through it in the absence of the infra-red image forming radiation. When the infra-red image arrives, it causes a drop of resistance in the layer 92. This results in the lowering of cut-off bias voltage in the apertured screen 94. Now the photoelectrons from layer 26 can pass through said member 94 and may be fed into electron multiplier 5 or its modifications, 80 or 83. The multiplied electron image has the pattern of the original infra-red image and is now projected or focused on the image reproducing screen

such as a luminescent screen 9-8 or on a target of a pick-up tube such as 30 or other targets or on a storage target.

My invention will allow the construction of a novel electron or other charged particles microscope such as proton or ion microscope or the diffraction cameras. One of the most vexing problems in the present electron microscopy is the damage of the examined specimen by the exposure to the electron beam. The electron beam causes irreversible changes in the structure of organic or inorganic objects as well. As a result images are obtained and recorded which in reality do not exist at all and represent artefacts only. The only way to eliminate or to reduce such artefacts is to decrease the intensity of the examining electron beam. The reduction of the intensity of the electron beam without prolonging the exposure time is unfortunately impossible because of the limited sensitivity of photographic materials used to record the electron-microscopic image. It is therefore, the objective of this invention to eliminate the artefacts by reducing either the strength of the electron beam irradiating the examined specimen or the exposure time or both.

FIGURE 19 represents the novel electron microscope 95. The microscope 95 has a source of electrons or of other charged particles 96, which may be an electron beam of hot filament type or of cold emission type. The emitted beam of electrons is collimated by the aperture 97 and is focused by the condenser lens 97a on the examined specimen 98. The specimen may be deposited on a supporting plate 98a with an opening therein or on a mesh as of silver.

The electron beam transmitted through the specimen is focused by the objective lens 97c on the plane of the projection lens 97b. In some cases it is preferable to use an intermediate lens between the objective lens and the projection lens. The projection lens provides the final enlargement of the electron image so that the enlarged image may now cover the whole area of the electron guide and multiplier 80. All lenses in this embodiment of the invention may be of the magnetic type or of electrostatic type.

The enlarged electron beam carrying the image of the examined specimen is projected or focused on the electron guide or multiplier such as 5 or its modifications, 80 or 83. It was found that the electron beam which carries the image of the examined specimen has to be considerably enlarged before focusing it on electron multiplier. The linear enlargement of the electron image should be higher than 10⁴. The multiplied electron beam which exits from the electron multiplier is projected or focused by fields 82a on an image reproducing screen such as a luminescent screen 9-8 or on a target 30 or other targets of a television pick-up tube, or on a photographic or xerographic plate. FIGURE 19 shows the electron or other charged particles microscope provided with a luminescent screen 9-8.

It should be understood that the novel electron or other charged particle microscopes may be also of electrostatic type. In such case the endface of the electron guide multiplier such as 5 or its modifications, 80 or 83, which faces the examined specimen should have a curved shape preferably of a concave configuration.

FIGURE 20 shows charged particles microscope 100 provided with a television pick-up device. The multiplied and enlarged electron beam carrying the image of the examined specimen is projected or focused on the target 30 described above or on a target of material exhibiting electron bombardment induced conductivity such as of As₂, Sb₃ or of Se or on a target of KCl. The read-out of the image is obtained by the use of the scanning electron beam 101 in the manner well known in the television art.

The image reproducing screen may be mounted normally to the long axis of the microscope or may be mounted at an angle to make it parallel to the exit endface of the electron guide and multiplier. In some cases

it is preferable to make the image reproducing screen of a curved shape.

The multiplied electron image is intensified as compared with original electron image by a factor of 10^4 – 10^6 . My devices permit therefore to reduce the intensity of the image forming electrons or other charged particles beam so that it will not damage the examined specimen, which was one of the objectives of this invention.

It should be understood that my invention applies also to emission type microscopes in which a source of the charged particles and the examined specimen are the same. All microscopes may use all modifications of electron multiplier 5, 80 or 83.

It is also understood that my invention covers the microscopes which use instead of electrons other charged particles such as ions or protons. It is also understood that my invention applies both to transmission type of all microscopes and to reflection type of all microscopes.

The novel image intensifying devices will be also very useful for images produced by radio-isotopes which emit gamma rays or beta-rays or other particles. One of such devices is shown in FIGURE 21. The image reactive screen 102 may comprise a fluorescent layer 24a which may be in a form of a continuous layer of adequate thickness or of a mosaic of small crystals. NaI (T1) is specially suited for gamma rays. The layer 24a may be mounted inside of the vacuum tube 103 or outside of vacuum tube. If it is mounted outside it may be deposited on the endwall 103a of the tube or may be adjacent closely to said wall 103a or may be separated from said wall with an optical system intervening between them. A photoemissive layer 26 one of the materials described above may be mounted directly on the fluorescent layer or mosaic 24a, if said layer 24a is inside of vacuum tube 103 or may be mounted on the inside surface of the endwall 103a if the fluorescent layer 24a is mounted outside of the tube 103. The photoemissive layer 26 may be also mounted within vacuum tube 103 on a radiation transparent support. The image reactive screen 102 if mounted within tube 103 may use as a supporting member the layer 25a. The supporting layer may be the first layer of composite screen 102 and must be therefore transparent to the image forming radiation and may be if used with gamma rays of material such as aluminum 23a. The supporting layer may be also mounted between the fluorescent layer 24a and photoemissive layer 26 in which case said layer 25a must be transparent to the fluorescent radiation and may be e.g. of glass, or suitable plastic such as silicone or polyester. The composite screen 102 may have a planar shape or a curved shape according to focusing fields which are used in the device.

It should be understood that all modifications of the composite screen 102 apply to all devices described in this specification. It should be also understood that the devices described and shown in FIGURES 21 and 21a may be used for images produced by all visible or invisible radiations and can be applied for images produced by X-rays, neutrons and infra-red, supersonic and other radiations.

The gamma or other radiation image is converted in the layer 24a into a fluorescent image. The fluorescent image is converted in layer 26 into a photoelectron image. The photoelectron image is projected or focused onto electron guide and multiplier 5 or its modifications 80 or 83, as was described above. The multiplied electron image exiting from said multiplier is projected or focused by electrostatic 109 or magnetic lenses on the endwall or partition wall 103b. The wall 103b forms or comprises a novel electron image conductor 105. The image conductor 105 comprises a plurality of electrically conducting members such as wires 106 which are embedded in an insulating matrix forming a two dimensional array. The diameter of wires may vary from a small fraction of one millimeter to a few millimeters. The insulating matrix 107 may be of a glass or a suitable plastic such as polyesters, fluorocarbons or polyethylenes. The wires 106 may be also coated with

an insulating coating before embedding them in the matrix 107. The insulating coating may end before one or both ends of wire 106 or may continue up to their end leaving only the end-points uncovered. The wires 106 coated or uncoated may extend beyond the free surface 108 of the matrix or may be flush with said surface 108 or may be on one or on both sides of the matrix recessed, which means that they terminate before reaching the free surface 108 of the matrix. In case the wires do not reach the surface 108 the remaining path to said surface may be filled with the matrix or may form an open channel according to the needs of the application. The thickness of the image conductor 105 may vary from a fraction of one millimeter to any size needed. The matrix 107 and wires 106 may be light transparent or opaque. The image conductor 105 may be of planar shape, may be of convex shape, or of concave shape, or of any other shape according to the application used. The electron beam from the electron multiplier 5 or its modifications is accelerated by the electrical fields 109 and is focused by focusing means on the image conductor 105. In some cases it is necessary to decelerate the electron beam before its entry into image conductor 105. The electrons which enter the wires 106 are conducted by them across the conductor 105 from the compartment A to the compartment B of the vacuum tube 103.

It was found that a space charge was formed at the image conductor 105 and it was preferable to provide on the wall 103b adjacent to the image conductor 105 an electrically conducting layer which allows the removal of said space charge.

It was found that the diameter of conducting members 106 does not control the definition of the images and that definition depends primarily on the size of the end points 106a.

It was further found that the spacing of the conducting members 106 does not affect the definition of images as long as the end-points 106a of conductors retains the same spatial relationship on their output side as it is on their input side.

If the electrons from the multiplier 5 or its modifications are after their exit accelerated to a high potential, they may exit from wires 106 into compartment B of the tube 103 and may be then utilized for read-out. The compartment B may have the construction of an image tube as shown in FIGURE 16 or of a television tube, or of a storage tube. The electron image may be stored in compartment B before its read-out by a scanning or a broad electron beam or by a light beam. The storage may be also accomplished by sending video signals which represent said image to a separate storage tube such as called "Kiloton" and which is manufactured by Raytheon Company of Waltham, Mass., or by feeding said video signals into a storage kinescope. It was found that in radio-isotope images a long storage time of signals is necessary because of a very low intensity of said signals and the use of storage means represents an important feature of this invention.

It should be understood that instead of having two compartments A and B in one vacuum tube 103 they may also be constructed in the form of two separate vacuum tubes, as it is shown in FIGURE 21a. In such case each tube is provided with its own image conductor 105 which are in contact with each other.

It should be understood that all modifications of device shown in FIGURE 21a in which two separate tubes 103 and 110 are used, apply also to the construction shown in FIGURE 21 in which one vacuum tube provided with two compartments A and B is used.

Another modification of my invention is shown in FIGURE 21a.

In many cases the potential of the electron or holes beam transmitted by the image conductor 105 or its modifications into the second vacuum tube 110 is so low that the electrons representing the image cannot exit from conductors 106. In such a case, a charge or potential image

is formed on the endpoints of conductors 106 and may be stored therein a time sufficient for the read-out of said image. The read-out of this stored electron image may be by means of a fast scanning electron beam, which produces secondary electron emission from the end-points of conductors 106. This secondary electron emission is modulated by the stored electron image at the end points of conductors 106a. The emitted secondary electrons may be next fed into electron multipliers and, after multiplication, may be converted into electrical signals in the manner well known in the television art. The end-points 106a of conductors 106 in some cases may be coated with a thin layer of secondary electron emitting material such as MgO, KCl, or Be in order to improve the output of secondary electrons. Another preferred read-out of the stored electron image in the conductors 106 may be accomplished by using a slow scanning electron beam. In this modification of the invention, the scanning beam 101a is decelerated in front of the conductors 106 by a retarding electrode. The decelerated electron beam is modulated by the electrical charge or potential image on the end-points of conductors 106. The returning modulated electron beam 101b is fed into electron multipliers and after multiplication, is converted into electrical signals such as video signals as it is well-known in the television art.

In another modification the endpoints of electrical conductors 106a may be coated with a photoemissive layer 26, such as of CsSb or of a multi-alkali antimony, such as K—Cs—Sb or K—Na—Cs—Sb. The photoemissive layer 26 may be in the form of a continuous layer or of a mosaic layer.

In some cases it is preferable to mount the photoemissive layer 26 on a very thin insulating layer interposed between the end-points 106a and said layer 26. The read-out of the electron image present in the conductors 106a may now be accomplished by means of a scanning light beam instead of a scanning electron beam. The scanning light causes emission of photoelectrons from the layer 26, point after point. This photoemission is modulated by the stored electron image in conductors 106. The emitted photoelectrons may be fed into multipliers and converted into electrical signals.

In another modification, the emission of photoelectrons from the layer 26 is produced by a broad and not by a scanning source of light. The broad emitted photoelectron beam may be stored in the target 30 of the television camera tube. The read-out from the target 30 occurs by means of a scanning electron beam which may be of a fast or of a slow type, as it is known in the television art.

In another modification the photoemissive layer 26 may be mounted on its own support such as mesh screen in a close proximity to the end-points of conductors 106. The photoemission of electrons from layer 26 will be modulated by the charge or potential image on said end-points 106a in the same manner as when using deposition of the layer 26 directly on said end-points 106a.

It was found that the use of the light beam for read-out improves the signals to noise ratio of the intensifying device as it removes the noise of the electron beam.

In another modification of my invention electron beam which is transferred by the image conductor 105 and which appears as a charge or potential image on the end-points of conducting members 106a can be read out by a broad non-scanning electron beam produced by an electron source. The broad electron beam passes through an aperture, is decelerated and irradiates the whole endface of the electron conductor 105 simultaneously in contradistinction to the scanning electron beam. The returning electron beam is modulated by the pattern of charges or potentials on conductors 106a. It is projected on the suitable image reproducing screen 8 such as of luminescent or electro-luminescent material which produces a visible image having the pattern of the original invisible image.

In another modification the broad electron beam after being modulated by charge image on conductors 106a is focused by electrostatic or magnetic means on the target 30 of television camera. The target 30 may be of a semi-conducting glass, MgO, Al₂O₃ or of a photoconductive material such as Sb₂S₃ or PbO or of material exhibiting electron bombardment induced conductivity such as MgO, or KCl. The broad electron beam is stored in the target 30 and can be read out by the scanning electron beam 101a from an electron source 100a. The electron beam 101a may be of a slow type or of a fast type and converts the stored image into video signals as it is known in the television art.

Another modification of X-ray of radio-isotope image intensifying devices is shown in FIGURE 22. In this embodiment the tube 113 is provided with the X-ray or gamma reactive screen 22 which may be of any construction described above but preferably it will be in the form of a mosaic or continuous screen 112 of a heavy metal such as lead, tungsten, or gold, or of copper. The screen 112 and the semi-conducting or dielectric television target 30a which may be of glass, magnesium oxide, aluminum oxide, potassium chloride or antimony sulphide forms with the screen 112 a closed vacuum-tight chamber C which is filled with a mixture of gases such as argon, neon, or xenon with organic gas compounds of poly-atomic type such as alcohol compounds.

The target 30a and the image reactive screen 112 are spaced close to each other. The separation between them may be as a fraction of 1 millimeter or a few millimeters and depends on the resolution of the image which is necessary.

The chamber C is connected to a D-C source 115 of electric power which provides voltage of 100 to 3000 volts. The impingement of X-rays or other ionizing radiation causes a self-quenching discharge of gas which produces electrical charges on the target 30a. The charges migrate to the opposite side of the target 30a and after the necessary storage time can be read out by an electron beam of a scanning type 101a or of a broad type or by a light beam, as was described above. This read-out converts the stored charges either into a visible image or into electrical signals for television transmission.

The discharge of gas is self-quenching, therefore a repeated build-up of the charges on target 30a may be achieved by a prolonged exposure to the image forming radiation. It was found that the gas in the chamber C must be replenished from time to time. For this purpose a sealed extension 114 is provided which can be reopened for injection of a new supply of gas and sealed again.

It should be understood that my device 113 may use a slow electron beam or a fast electron beam for a read-out. Furthermore it should be understood that this device may be used for neutrons and other atomic particles images.

It should be understood that the word "glass" in claims embraces all kinds of glasses and of plastic materials as well.

It should be understood that the word "light" in claims embraces all visible and invisible radiations.

It should be understood that word "tunnels" in this specification and in the appended claims means passages which have walls completely surrounding said passages leaving only the end-faces open. It is in contradistinction to "channels" which are not surrounded by walls on all sides.

In another modification of my device the voltage supplied to the gas chamber is high enough to cause a Townsend type of discharge when said gas chamber is struck by an ionizing radiation. The image reactive screen may be 22, 112 or any one of the described above. The impingement of ionizing radiation on the image reactive screen produces emission of atomic particles or of gamma rays therefrom which produces again sparks or light flashes in the gas. The light flashes corresponding to

gamma or X-ray image are conducted by the fiberoptic partition 12, such as described above, from the compartment C to the photoemissive layer 26 which is mounted on the opposite side of said fiberoptic partition. The sparks image is therefore transported to the photoemissive layer 26 without a loss of resolution and is converted now in the photoelectron image which has the pattern of the original invisible image. The photoelectron image can be next accelerated by electrical fields and focused on the image reproducing screen 8-9 and will be converted there into a visible luminescent image.

In another modification the photoelectron image can be focused on the target 30 or 30a of the television pick-up tube type and may be converted into electrical signals for television on transmission. It should be understood that television pick-up compartment may be of any type described above.

It should be also understood that the photoelectron image may be first fed into electron guide and multiplier 5 or its modifications 80 or 83 before its conversion into a visible image or into electrical signals.

As various possible embodiments might be made of the above invention, and as various changes might be made in the embodiment above set forth, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. A vacuum tube for producing images comprising in combination means for receiving an image, said means comprising a source of electrons mounted in said tube and producing a beam of electrons corresponding to said received image, and a device for receiving and multiplying said electron beam, said device comprising a plurality of separate individual hollow members containing empty tunnels and having tubular cross-section and curved configuration along the longitudinal axis of said members, said curved configuration being uni-directional, said members having their own individual walls surrounding said tunnels, said walls furthermore being continuous over the entire length of said electron multiplying device, said tunnels having entrance apertures for the entrance of said beam of electrons and exit apertures for the exit of electrons, the walls of said tunnels comprising secondary electron emissive material on the inside surface of said tunnels so that said entering electrons strike the walls of said tunnels and produce a multiplied beam of electrons, said members having their longitudinal diameter larger than their cross-sectional diameter, said members being combined together in one array, said device comprising in addition electrically conducting means mounted in cooperative relationship with said members, said vacuum tube comprising furthermore means for receiving and utilizing said beam of electrons exited from said apertures, said utilizing means and said source of electrons mounted opposite to each other.

2. A vacuum tube as defined in claim 1 which comprises luminescent means for receiving said exited electrons, said luminescent means provided with an electron transmitting light reflecting layer, said layer preventing the back-scatter of light emitted by said luminescent means.

3. A vacuum tube as defined in claim 1 which comprises a composite screen having luminescent means and photoelectric means.

4. A vacuum tube, as defined in claim 1 in which said means receiving an image comprise means reactive to X-rays and emitting electrons in response to said X-rays.

5. A device as defined in claim 1, in which said hollow curved members are substantially of the same length.

6. A vacuum tube as defined in claim 5, in which said array of said hollow members has two endfaces and

in which at least one of said endfaces has a slanted configuration.

7. A vacuum tube as defined in claim 1, in which walls of said hollow members comprise an electrically semi-conducting material.

8. A vacuum tube as defined in claim 1, in which said source of electrons comprises an electron gun.

9. A vacuum tube as defined in claim 1 which comprises an endwall provided with a plurality of members conducting light by internal reflection of said light in said members and constituted of material of a high index of refraction transparent to said light, said members having own coating means of material of a lower index of refraction than said members.

10. A vacuum tube as defined in claim 1, in which the walls of said hollow members are resistant to the temperature of 600° C.

11. A vacuum tube as defined in claim 1, in which said hollow members are provided on the outside surface of their walls with cladding means which have a lower melting point than said walls.

12. A vacuum tube as defined in claim 11, in which said hollow members have substantially the same length.

13. A vacuum tube as defined in claim 11, in which said means receiving an image comprise X-ray sensitive means.

14. A device for receiving and multiplying an electron beam, said device comprising a plurality of separate individual hollow members containing empty tunnels and having tubular cross-section and curved configuration of the longitudinal axis of said members, said curved configuration being uni-directional, said members having their own individual walls surrounding said tunnels, said walls furthermore being continuous over the entire length of said electron multiplying device, said tunnels having entrance apertures for the entrance of said beam of electrons and exit apertures for the exit of electrons, the walls of said tunnels comprising secondary electron emissive material on the inside surface of said tunnels so that said entering electrons strike the walls of said tunnels and produce a multiplied beam of electrons, said members having their longitudinal diameter larger than their cross-sectional diameter, said members being combined together in one array, said device comprising in addition electrically conducting means mounted in cooperative relationship with said members.

15. A device as defined in claim 14 in which said walls comprise glass heat stable at the temperature of 600° C.

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