Dec. 24, 1957 E. E. SHELDON 2,817,781

IMAGE STORAGE DEVICE

Filed May 27, 1954 3 Sheets-Sheet 1

Fig. 1

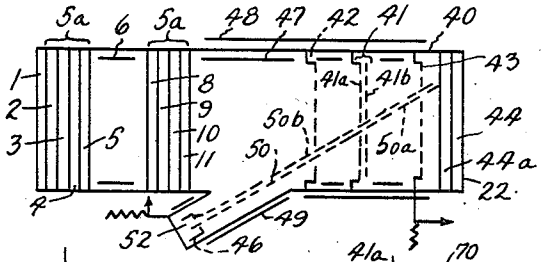
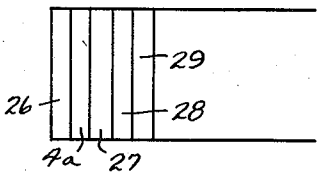


Fig. 7



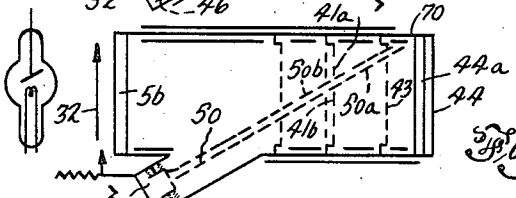
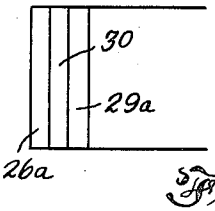


Fig. 2

Fig. 8



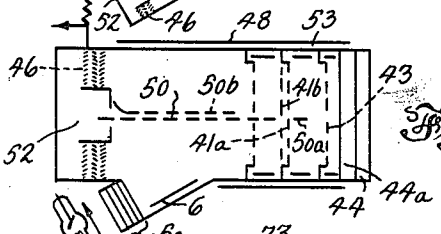
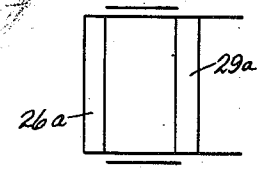


Fig. 4

Fig. 9



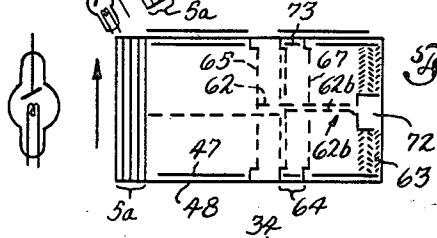


Fig. 5

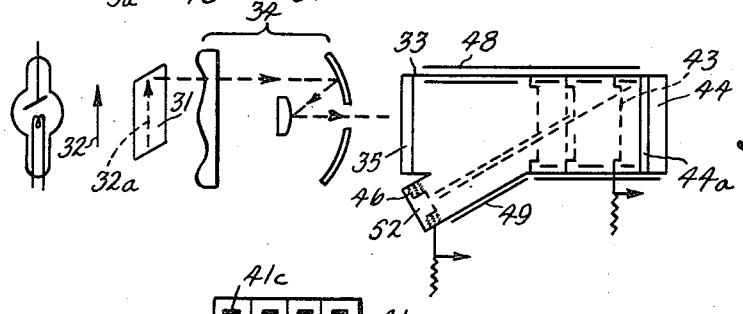


Fig. 3

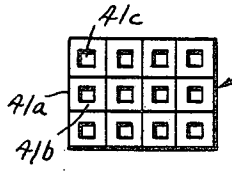


Fig. 6

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IMAGE STORAGE DEVICE

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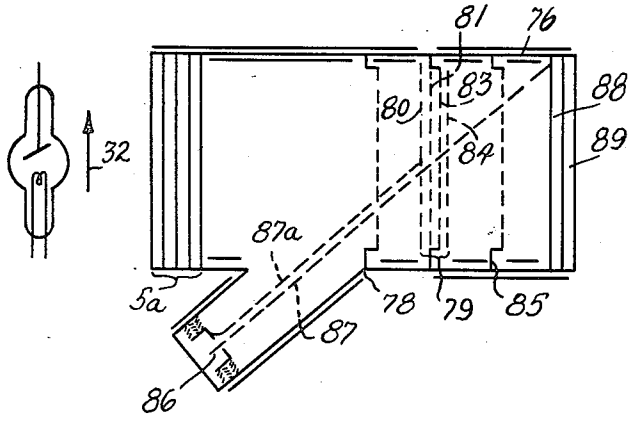


Fig. 10

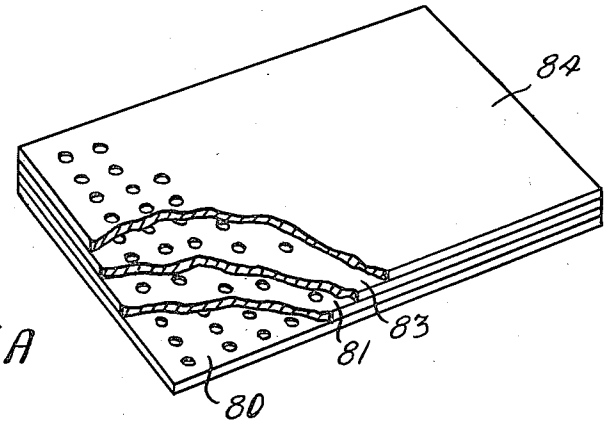


Fig. 6A

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IMAGE STORAGE DEVICE

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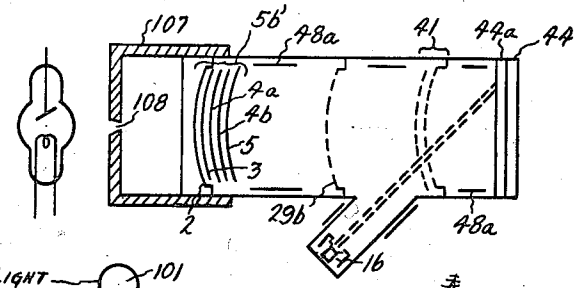


Fig. 11

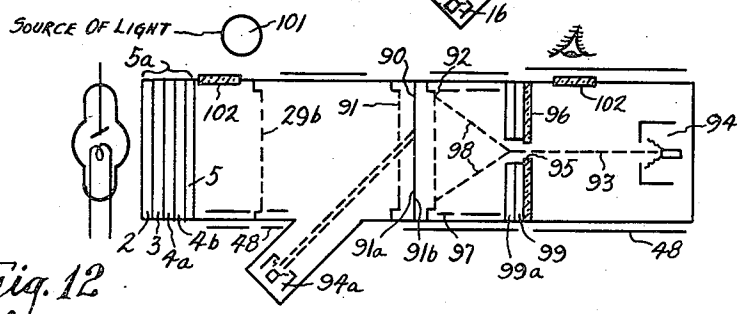


Fig. 12

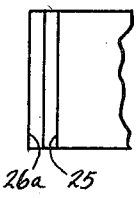


Fig. 16

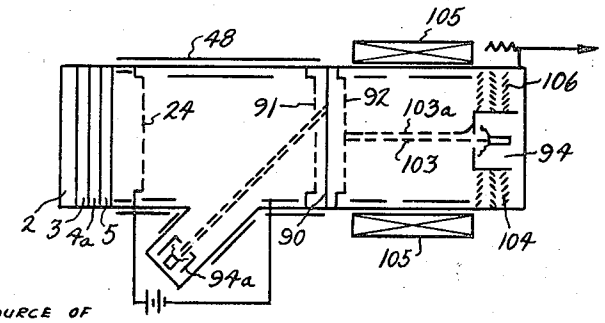
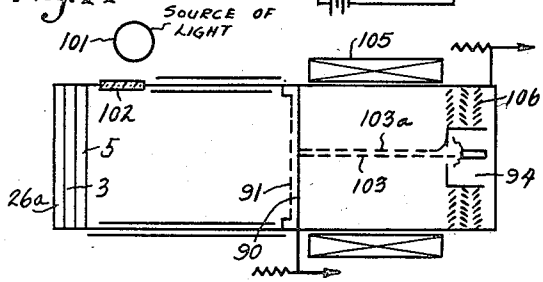


Fig. 13

Fig. 14



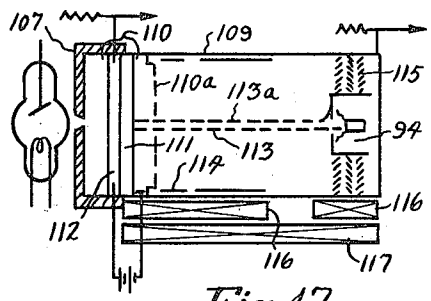


Fig. 17

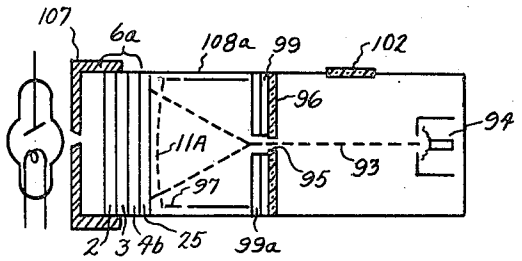


Fig. 15

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United States Patent Office

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2,817,781

IMAGE STORAGE DEVICE

Edward Emanuel Sheldon, New York, N. Y.

Application May 27, 1954, Serial No. 432,748

5 Claims. (Cl. 313—65)

This invention relates to an improved method and device for intensifying images and refers more particularly to an improved method and device for intensifying images formed by the impingement of invisible radiations which term is meant to include X-rays and other invisible radiations such as ultra-violet, infra-red, gamma rays and the like and also irradiation by beams of atom particles such as e. g. neutrons on a fluorescent or other reactive screen.

This application has a common subject matter with my following U. S. Patents: No. 2,555,423, filed April 16, 1947, and issued June 5, 1951; No. 2,699,511, filed May 4, 1951 and issued January 11, 1955 and No. 2,717,971, filed March 30, 1949 and issued September 13, 1955.

One primary object of the present invention is to provide a method and device to produce intensified images. This intensification will enable to overcome the inefficiency of the present fluoroscopic examinations. At the present level of illumination of the fluoroscopic image the human eye has to rely exclusively on scotopic (dark adaptation) vision, which is characterized by a tremendous loss of normal visual acuity in reference both to detail and to the contrast.

Another object of this invention is to make it possible to prolong the fluoroscopic examination since it will reduce markedly the strength of radiation affecting the patient's body. Conversely, the exposure time or energy necessary for the radiography may be reduced.

Another object is to provide a method and device to store X-ray images which was not possible until now.

The present intensifying devices concerned with reproduction of X-ray images are completely unsatisfactory, because at low levels of fluorescent illumination, such as we are dealing with, there is not enough of X-ray photons to be absorbed by fluorescent or photoelectric screens used in such devices. Therefore the original X-ray image can be reproduced by them only with a considerable loss of information. It is well known that the lack of sufficient number of X-ray quanta cannot be remedied by the increase of intensity of X-ray radiation, as it will result in damage to the patient's body. This basic deficiency of the X-ray examination was overcome in my invention by using an X-ray exposure of a strong intensity but of a short duration, and storing the invisible X-ray image for subsequent inspection of the desired length of time without any need of maintaining the X-ray irradiation. The X-ray beam, therefore, can be shut off while reading the stored X-ray image and in this way the total X-ray exposure received by the patient is not increased, in spite of using bursts of a great X-ray intensity.

In order to obtain the objects of this invention a special X-ray sensitive image tube had to be designed, Fig. 1. This novel X-ray image tube is characterized by elimination of the optical lens system present in other image tubes which resulted in 20–30 fold gain in the light reaching the photo-cathode. Then by the combined use of a novel photoemissive pick-up system and storage system of the tube, of an electron multiplier section of the tube, of a

novel electron image amplifier section of the electronic acceleration and of the electronic image diminution the intensification of the luminosity of the original image exceeding the ratio of 1000–1 was accomplished.

The elimination of the optical system present in other image tubes to focus the fluorescent image on the photocathode of the tube was accomplished by positioning within the X-ray sensitive image tube of the screen, consisting of combination of X-ray transparent, light reflecting layer, of X-ray fluorescent, or reactive layer, and of the photoemissive layer. All layers are placed in close apposition to each other to prevent the loss of definition. The fluorescent and photoemissive layers are separated only by a very thin light transparent, chemically inactive, barrier layer of a thickness not exceeding 0.15 millimeter. the previous combinations of fluorescent and photoemissive layers were not successful because of detrimental chemical interaction of both layers, due to lack of a barrier between them, therefore the introduction of light transparent barrier layer represents a very important part of this invention. The photoemissive layer is of semi-transparent type. This layer is characterized by emission of electrons on the side opposite to the side of the incident light. The photoelectrons emitted from the photoemissive layer in a pattern corresponding to the incident light pattern are accelerated and focused by means of magnetic and/or electric fields on the novel image amplifying system.

The amplification section of the tube consists of one or a few screens each of them composed of a very thin light-reflecting, electron pervious layer, of a fluorescent layer, and of a photoemissive layer in close apposition to each other. It is necessary to include a very thin light transparent, chemically inactive barrier layer between the fluorescent and photoemissive layers in order to prevent their chemical interaction, which should be of a thickness not exceeding 0.15 millimeter but preferably much less. The electrons from the pick-up section of the image tube are focused by magnetic or electrostatic fields on the fluorescent layer of a screen described above. The luminescence of the fluorescent layer of the amplification screen will cause the emission of electrons from the photoemissive layer of the screen. This process can be repeated a few times, using a few screens described above resulting in 10–100 times intensification of the original electron image.

In another modification to be used in this invention there is an additional multiplier section which consists of a multiplier and can give an additional intensification of the electron image by secondary electron emission.

The electrons leaving the amplifying section are accelerated by means of high voltage electro-static fields. The accelerating system can be of a conventional type well known in the art. Much better results with higher voltages will be achieved with an electrostatic multi-lens system. Next the electron image is stored in the special storage target. The storage of the electron image allows the inspection of the X-ray image for a desired time without the need of maintaining X-ray irradiation during the reading. This saves so much energy in X-ray exposures that the patient's body will not be impaired even with prolonged examination.

Next the electron image is demagnified which results in its additional intensification. The electron diminution of the image, in order to gain its intensification is well known in the art, therefore does not have to be described in detail.

The diminished electron image is projected on the fluorescent screen at the end of the tube where it can be viewed by the observer directly or by means of an optical magnifying eye piece, through the light transparent end wall of the tube.

The combination of the above described features of the X-ray sensitive image tube allows to obtain intensification of the original X-ray image which was the primary objective of this invention. Having such a marked intensification of the original X-ray image it will be possible now to use a much finer grain of fluorescent screens than was practical until now and to improve this way detail and contrast of the final image, which was another purpose of this invention.

The invention will appear more clearly from the following detailed description when taken in connection with the accompanying drawings by way of example only, preferred embodiments of the inventive idea.

In the drawings:

Fig. 1 is a cross-sectional view of the X-ray image storage tube.

Fig. 2 is a cross-sectional view of a modification of the X-ray image storage tube.

Fig. 3 is a cross-sectional view of the X-ray storage image tube in combination with optical system.

Fig. 4 is a cross-sectional view of a modification of the X-ray image storage tube.

Fig. 5 is a cross-sectional view of a modification of the X-ray image storage tube.

Figs. 6 and 6*a* show a plan view of the storage target.

Fig. 7 is a diagrammatic view of the neutron sensitive photocathode to be used in neutron storage tube.

Figs. 8 and 9 show a modification of an X-ray or a neutron sensitive photocathode.

Fig. 10 is a cross-sectional view of a modification of the X-ray image storage tube.

Fig. 11 shows a modification of the storage tube using electrostatic focusing system.

Fig. 12 shows a modification of the storage tube using an imperforated storage target.

Fig. 13 shows a storage tube adopted for transmission of images.

Fig. 14 shows a modification of the storage tube with an imperforated target.

Figs. 15 and 16 shows a tube having photocathode of photoconductive type.

Fig. 17 shows a modification of photoconductive photocell.

The face **1** of the image tube **40** shown in Fig. 1 must be of a material transparent to the type of radiation to be used. Inside of the face of the tube there is a very thin visible light reflecting, X-ray transparent layer **2** such as of aluminum or light diffusing layer such as of titanium oxide which prevents the loss of light from the adjacent fluorescent layer **3**. An extremely thin barrier layer **4** separates the fluorescent screen **3** from the adjacent photoemissive layer **5**. The reflecting layer **2**, the fluorescent layer **3**, the separating layer **4**, and photoemissive layer **5** form together a composite photocathode **5***a* which converts X-ray images into electron images. In some cases the composite photocathode must be of convex shape instead of flat type, as will be explained below. The fluorescent layer **3** and the photoemissive layers **5** should be correlated so that under the influence of the particular radiation used there is obtained a maximum output of photoemission. More particularly the fluorescent layer should be composed of a material having its greatest sensitivity to the type of radiation to be used, and the photoemissive material likewise should have its maximum sensitivity to the wave length emitted by the fluorescent layer. Fluorescent substances that may be used are willemite, or other zinc silicates, $BaPbSO_4$, zinc selenides, zinc sulphides or calcium tungstate, with or without activators. The satisfactory photoemissive materials for the composite photocathode will be caesium oxide, caesium oxide activated by silver, caesium with antimony, caesium with tellurium, bismuth or arsenic or antimony, with lithium or potassium. The barrier layer **4** between the fluorescent and photoemissive surfaces can be an exceedingly thin transparent film of glass, of ZnF_2,

of silicon, tin oxide, tin chloride or of a suitable plastic such as polyesters, e. g. Mylar made by DuPont Company in U. S. A., or of a conducting material such as known in the trade under the name "Nesa" made by Pittsburgh Plate Glass Company.

In order to prevent chemical interaction between the photoemissive and fluorescent layer, I found that light transparent layer must be of a thickness not less than 0.5 microns and preferably of 1 micron. It is also desirable to provide in some cases a light transparent layer which is electrically conducting and which may serve as a conducting base for the proper functioning of the photoemissive layer **5**. I found that conducting layers loose their transparency when they are made thicker than 0.1 micron. On the other hand the light transparent separating layer if made of dielectric material such as silica or Mylar remains transparent regardless of its thickness. Therefore in some embodiments of the invention the separating layer is composed of two layers, one of dielectric material *4a* which provides the protective barrier and the other layer *4b* of conducting material which helps the function of the photoemissive layer **5**.

The thickness of the separating layer should not exceed 0.15 millimeter, but preferably should be less than 25 microns to preserve definition of images. The light transparent separating layer **4** in the photocathode **5***a* may be deposited on the fluorescent layer **3** so that it doesn't require any support by the walls of the tube. In modification of the composite photocathode the light transparent layer **4** such as of Mylar may be attached to the walls of the tube by means of metallic rings and may provide then support for other layers. In another preferred modification the fluorescent layer **3** is embedded in the plastic such as Mylar which has a great tensile strength. The fluorescent layer embedded in Mylar is self-supporting and can serve also as a support for other layers of the composite photocathode. Mylar can be dissolved in a proper solvent. Therefore it may be made of any desired thickness so that the top of Mylar layer outside of the fluorescent layer which will now serve as a light transparent separating layer may be made of a thickness of the order of microns as it is necessary for the best resolution of the reproduced image.

The use of plastic embedded fluorescent layer has a great advantage over the glass embedded fluorescent layer because the thickness of the plastic outside of the fluorescent layer can be controlled up to microns which cannot be done when using glass. This construction is especially suitable for the composite screen used as a second stage as shown in Fig. 1. It may be added that Mylar will withstand processing of the vacuum tube.

The electron image obtained in the pick-up section is now accelerated by electrodes **6** and is transferred to the first screen of the amplifying section by means of focusing magnetic or electrostatic fields which are not indicated, since they are well known in the art and would only serve to complicate the illustration. The amplifying section uses one or a few successively arranged composite screens *5a* each of them consisting of an electron pervious, light-reflecting layer **8**, of a fluorescent layer **9**, of light transparent barrier layer **10**, and of photoemissive layer **11**. Fluorescent substances that may be used are willemite or other zinc silicates, zinc selenides, zinc sulphide or calcium tungstate with or without activators. The satisfactory photoemissive materials will be caesium oxide, caesium oxide activated by silver, caesium with antimony, with bismuth or arsenic or antimony with lithium or potassium. The barrier layer **10** between the fluorescent and photoemissive surfaces was described above and may be of the same type. The amplification achieved by this system results in marked intensification of the original image.

In some applications it may be preferable to use in conjunction with amplifying system the electron multiplier section consisting of one or a few stages of sec-

ondary electron multipliers which serves to intensify further the electronic image. In such a case the electron image from the pick-up section of the tube is focused by means of magnetic field on the first stage of the multiplier section. The secondary electrons from the first stage are focused the same way on the second stage of the multiplier section and so on. CsO:Cs or Ag:Mg multipliers provide a good secondary electron emission.

The electrons emerging from the amplifying section are now accelerated and imaged by means of fields **47** to the desired velocity, giving thus further intensification of the electron image. Next the electron image is diminished by means of electromagnetic or electrostatic lenses to the desired size, resulting in image intensification proportional to the square power of the linear diminution and is projected on the storage target.

The use of a storage target improves markedly signal to noise ratio resulting in pictures of much better detail and contrast. The storage target is shown in Fig. 6 and consists of a thin perforated metal sheet or of woven conducting wire mesh *41a*. On the side of the target opposite to the photocathode there is deposited by evaporation storage material such as CaF_2, *41b* in such a manner that openings *41c* in the target should not be occluded. In some cases on the side of the target facing the photocathode there is deposited by evaporation a thin metal coating.

Between the photocathode and the storage target, in a close spacing to the target, there is mounted a fine mesh conducting screen **42**. On the side of the storage target, opposite to the photocathode there is disposed a meshed metal electrode **43**, which repels electrons during the writing phase of operation and attracts electrons during the reading phase. Adjacent to said meshed metallic screen there is disposed a fluorescent screen **44** provided with a metallic light reflecting electron transparent layer *44a* such as of aluminum. The reflector electrode **43** during writing is kept at the potential negative to the photocathode *5a*. Therefore the photoelectrons transmitted through the perforated target are repelled by said reflector electrode and have to fall back on the storage target **41** and deposit thereon varying charges at successive points according to the pattern of X-ray image. The best way of operating my system is to have the storage target surface at zero potential or at photocathode potential and then to write on it positive which means to deposit positive charges. This can be accomplished by adjusting the potential of the surface of the storage target so that its secondary emission is greater than unity.

The photoelectrons having the pattern of X-ray image after passage through openings in the target are repulsed back by the reflector electrode **43** because in this phase of operation its potential is lower than that of the storage target. The impingement of photoelectron beam causes secondary electron emission from the target **41** greater than unity. The secondary electrons are drawn away. As a result a positive charge image is formed on the perforated target **41** having the pattern of the original X-ray image. This charge image can be stored in the target as long as 50 hours, if the storage material is CaF_2.

In the reading phase of operation of my device the target **41** is scanned by a slow electron beam **50** from the electron gun **52**. The electron beam is focused by magnetic or electrostatic fields **49** and is decelerated by the electrode **42** which may be in the form of a ring or of meshed screen. The deflecting fields and synchronizing circuits are not shown in order not to complicate the drawings. It is obvious that all fields controlling the scanning beam are inoperative during the writing phase of the operation. In the same way the fields controlling the photoelectron beam are not operating during the reading phase of the operation. A part of the scanning electrom beam *50a* passes through the perforations *41c* in the target **41**. The charge image on the target controls the passage of the scanning electron beam *50a* acting in the similar manner to a grid in the electron tube.

The electron beam **50** in the reading phase of operation passes through the openings in the target **41**,, is modulated by the stored charges on it and strikes the fluorescent screen **44** producing thereby a light image having the pattern of the original X-ray image. The fluorescent screen **44** is provided with an electron transparent, light-reflecting backing *44a* such as of aluminum. At the same time the open mesh metallic screen **43** may be used as a collector for electrons to be converted into video signals and transmitted to distant receivers. In case no transmission of stored image is desired the image reproduced on the fluorescent screen **44** can be markedly intensified by using instead of the scanning electron beam a broad electron beam from the electron gun **52** covering all storage target **41** of a flat ribbon scanning beam covering one line of the image.

Video signals can be obtained not only from the transmitted electrons of the scanning beam but as well from the electrons *50b* of said scanning beam returning to the electron gun. This part of the electron beam is also modulated by the charge image on the target **41** but is of reverse polarity than the transmitted electrons. The non-transmitted part of the scanning electron beam returns to the multiplier section **46**. They are multiplied there and then are converted into video signals. This arrangement by using multiplication of electrons allows a marked intensification of video signals. The returning electron beam *50b* contains two groups of electrons. One group are electrons which are reflected specularly from the target. Another one are electrons which are reflected non-specularly it means were scattered. These two groups can be separated from each other before reaching the multiplier. There are many ways to separate these two groups of electrons, all well known in the art. The best method is to introduce an additional helical motion into a primary scanning beam. Then the scattered electrons in the returning beam will be on one side of the specularly reflected electrons. Therefore it will be possible to direct scattered electrons into aperture of the multiplier, while stopping the reflected electrons by the edge of the multiplier aperture. The use of the scattered electrons increases markedly sensitivity of the system because it reduces the inherent shot noise of the scanning electron beam.

Video signals have the pattern of the original X-ray image. They are amplified and transmitted by coaxial cable or by high frequency waves to receivers. Receivers may be of various types such as kinescopes, facsimile receivers, in combination with electrographic cameras and others may be used to reproduce images for inspection or recording. The accelerating, focusing, and deflecting fields as well as synchronizing circuits are not known as they are well known in the art and would only complicate drawings.

After the stored image has been read and no further storage is desired it may be erased by the use of the scanning electron beam **50** by adjusting the potential of the storage target to the value at which the secondary electron emission of its storing surface is below unity. In such a case the target will charge negatively to the potential of the electron gun cathode. The potential of the reflector in the erasing phase of operation must be more negative than that of the storage target, so that the scanning electron beam will be repelled to the target.

It should be understood that instead of composite photocathode *5a* a single layer photocathode *5b* of a material emitting electrons when excited by X-rays such as of lead, gold, bismuth or uranium may be used. This modification is shown in Fig. 2. The operation of the X-ray image tube **70** is similar to the tube **40** described above. The only difference being that in this tube the photoelectron image having the pattern of the X-ray image is deposited as a positive charge image on the storing surface *41b*

of the storage target facing the photocathode. The photoelectron image may be deposited on the opposite side of the target, as well, if a reflector electrode of mesh **43** is provided for this purpose as was explained above.

In another modification of my invention shown in Fig. 3 the X-ray image is converted into a fluorescent image **32***a* in the fluorescent screen **31** outside of the X-ray image storage tube **33**. The fluorescent image is projected by an optical system, preferably of a reflective type **34** on the X-ray storage tube having a photocathode **35** of a material emitting electrons such as of CsSb, CsOAg, or of lithium or potassium on antimony or bismuth. The fluorescent image projected on the photocathode produces a photoelectron image. The rest of the operation of this X-ray storage tube is the same as described above.

It should be understood that the storage surface **41***b* may be deposited on the side of the target **41** facing the photocathode or on the opposite side of said target in all my embodiments of invention. It is also to be understood that in case in which the storage surface **41***b* is facing the photocathode, the reflector electrode **43** should be eliminated as it serves then no purpose and causes only deterioration of the image.

It should be understood that the composite photocathode, the electron gun and the perforated target may be disposed in many different ways and it is to be understood that the various modifications of their mutual arrangement come within the scope and spirit of my invention. One of such modifications is shown by way of example only in Fig. 4. The X-ray image tube **53** operates in the same way as the tube **70**, the only difference being the photoelectron image is projected on the storage target at an angle which requires the use of arcuate focusing fields.

Another modification of X-ray storage tube in which the photocathode and electron gun are disposed at the opposite ends of the tube is shown in Fig. 5. This arrangement is suitable only for converting the stored X-ray images into video signals and cannot be used for immediate reproduction of X-ray images in the same tube. In this modification of my invention, shown in Fig. 5, the invisible X-ray image of the examined object **32** is converted by the composite photocathode **5***a* which has been described above into a photoelectron image. The photoelectron image is accelerated by the electrode **47** and is focused by the magnetic or electrostatic fields **48** on the perforated storage target **64**, also described above.

Between the photocathode and the storage target, in a close spacing to the target, there is mounted a fine mesh conducting screen **65**. On the side of the storage target, opposite to the photocathode there is disposed a meshed metal electrode **67**. The reflector electrode **67** during writing is kept at the potential negative to the photocathode **5***a*. Therefore the photoelectrons transmitted through the perforated target are repelled by said reflector electrode and have to fall back on the storage target **64** and deposit thereon varying charges at successive points according to the pattern of the X-ray image. The photoelectron image may be also stored on the side of the storage target facing the photocathode as was explained above. In such a case the storing surface should face the photocathode and the mesh electrode **67** is eliminated, as it is not necessary. The best way of operating my system is to have the storage target surface at zero potential or at photocathode potential and then to write on it positive it means to deposit positive charges. This can be accomplished by adjusting the potential of the surface of the storage target so that its secondary emission is greater than unity.

The photoelectrons having the pattern of X-ray image after passage through openings in the target are repulsed back by the reflector electrode **67** because in this phase of operation its potential is lower than that of the storage target. The impingement of photoelectron beam causes secondary electron emission from the target **64** greater than unity. The secondary electrons are drawn away by the mesh screen **64***a* of the storage target which is connected to the source of positive potential. As a result a positive charge image is formed on the perforated target **64** having the pattern of the original X-ray image. This charge image can be stored in the target as long as 50 hours, if the storage material is CaF_2.

In the reading phase of operation of my system the target **64** is scanned by a slow electron beam **62** from the electron gun **72**. The electron beam is focused by magnetic or electrostatic fields **71** and is decelerated by the electrode **73** which may be in the form of a ring or of meshed screen. The deflecting fields and synchronizing circuit are not shown in order not to complicate the drawing. It is obvious that all fields controlling the scanning beam are inoperative during the writing phase of operation. In the same way the fields controlling the photoelectron beam are not operating during the reading phase of the operation. A part of the scanning electron beam passes through the perforations in the target **64**. The charge image on the target controls the passage of the scanning electron beam **62** acting in the similar manner to a grid in the electron tube.

It is obvious that all fields controlling the scanning beam are inoperative during the writing phase of the operation. In the same way the fields controlling the photoelectron beam are not operating during the reading phase of the operation. The scanning electron beam **62** is modulated by the stored charge image. A part of it, **62***a*, is transmitted through the openings in the storage target **64**, is collected by the mesh electrode **65** and is converted into video signals in the usual manner. Another part, **62***b*, of the scanning electron beam is returning to the electron gun **72**, is diverted to the multiplier **63** and after multiplication therein is converted into video signals. Video signals have the pattern of the original X-ray image and are amplified and transmitted by coaxial cable or by high frequency waves to receivers. Receivers may be of various types such as kinescopes, fascimile receivers, in combination with electrographic camera, and others may be used to reproduce images for inspection or may be photographed or recorded.

In some cases it may be more desirable to have the fluorescent screen **44** mounted outside of the vacuum tube, in such cases thin electron transparent layer of chromium or aluminum is placed on the end wall **22** of the vacuum tube made of fernico glass. The image appearing on the fluorescent screen can be viewed directly or by means of an optical eye-piece giving the desired optical magnification of the image. In other cases the fluorescent screen **44** is substituted by electrophotographic layer or by photographic layer in combination with fluorescent screen, or by an electrographic plate, permitting thus to obtain a permanent record of electron image.

In another alternative of this invention the X-ray image tube is curved and the electron beam is deflected by proper magnetic or electrostatic fields. This arrangement will prevent the positive ions from reaching the photoemissive section.

It is not intended to restrict the scope of this invention to the employment of X-ray or gamma radiations but other corpuscular radiations and suitable reactive layers are intended to be comprehended. Another form of the invention is illustrated in Fig. 7, wherein a neutron reactive layer **26** preferably from the group boron, lithium, gadolinium and uranium or of paraffine is placed within the image tube to act as a photocathode. The protons or electrons liberated from this layer **26** under the impact of neutron radiation will strike directly or in some cases through an additional thin electron pervious chemically inactive barrier layer **4***a'*, a suitable fluorescent layer **27**, causing it to fluoresce and acti-

vate a suitable photoemissive layer 29 through the light transparent barrier layer 28. In other cases a neutron reactive layer of cadmium or copper will be more advantageous, because of its gamma emission. In some cases when the definition of reproduced images is not critical, the fluorescent layer 27 may be placed outside of the tube on its face 1.

In some cases it may be more desirable (Fig. 8) to eliminate the fluorescent layer 27 and to cause protons or electrons from the layer 26*a* to act on electron emissive layer 29*a* either by apposition, or through an electron pervious chemically inactive barrier layer 30 which may be sometimes used either to prevent chemical interaction of adjacent layers or to slow down atomic particles from the layer 26*a*. In other cases it is preferable to focus protons or electrons or alpha particles from the layer 26*a* on electron emissive layer 29*a* with magnetic or electrostatic fields (Fig. 9). It should be understood that all modifications apply to X-ray or gamma images as well. In case of X-ray images layer 26*a* should be preferably of gold, lead or bismuth.

The fluorescent layer to be used in the neutron sensitive tube may be of similar composition as described above in the X-ray sensitive image tube, but it has also to be adapted to respond most efficiently to the radiation emitted from neutron sensitive layer by enriching it with proper neutron reactive elements such as boron or gadolinium. The photoemissive layer has again to be correlated with spectral emission of fluorescent layer. The amplifying system, the multiplier system, the storage system, the electronic diminution are the same for neutron sensitive image tube and for X-ray sensitive image tube.

In another modification of my invention shown in Fig. 10 the X-ray sensitive pick-up tube 76 has a composite storage target 79 shown in Fig. 6*a*. The X-ray image is converted in the photocathode 5*a* described above into photoelectron beam having the pattern of the X-ray image. The photoelectron image is accelerated and focused on the perforated storage target 79. The target consists of a thin perforated light transparent dielectric such as glass 83. Also a metallic mesh screen can be used instead of a perforated glass. In such a case however, a light transparent dielectric must be deposited on the mesh screen and in such a manner that openings in the screen remain unobstructed. On the side of the glass layer 83 facing the photocathode is deposited a fluorescent layer 81 also in such a manner that the openings in the glass are unobstructed. On the side of the fluorescent layer is deposited a light reflecting layer 80 such as of aluminum. On the side of the dielectric layer 83 which is away from the photocathode is deposited a photoemissive layer 84 in such a manner that openings in the dielectric layer are not obstructed.

The photoelectron beam causes fluorescence of the layer 81. The fluorescent light passes through glass layer 83 and causes emission of electrons from the photoemissive layer 84. The emitted photoelectrons are led away by adjacent collecting mesh screen 85. As a result a positive charge image is stored on the layer 84. This stored charge controls the passage of the scanning electron beam 87 in the same manner as was described above. The transmitted electrons of the scanning beam will strike the fluorescent screen 89 having a light reflecting electron transparent backing 88 and will reproduce therein the X-ray image. The transmitted electrons are focused on the fluorescent screen 89 by means of magnetic or electrostatic fields which are well known in the art.

It should be understood that the storage tubes shown in Figs. 1, 3, 4, 7, 8, 10, 11, 12, 13 and 14 may be markedly simplified by eliminating the electron gun 52 and by using as a reading electron beam, the electron beam produced by the photoemissive layer 5 or 35. This may be accomplished by irradiating the photoemissive layer 5 or 35 with a source of light 101 from outside in the image reading phase of operation.

Storage of X-ray images may also be accomplished by using a light image feed-back system. The fluorescent X-ray image in this modification of my invention is reproduced on the face of the image tube as was explained above. Before it begins to fade it is projected on a television pick-up tube and produces an electrical image therein. The electrical image is converted by the pick-up tube into video signals in the manner well known in television. For the purposes of this invention any type of television pick-up tube such as photoemissive type, photoconductive type, or of photovoltaic type may be used. Video signals are sent from the pick-up tube to the kinescope and reproduce there the fluorescent image. The fluorescent image from the kinescope may be again projected on the pick-up tube to produce again an image therein. In this way an endless stream of fluorescent light images is produced so that the fluorescent image may be inspected for a desired time without maintaining the X-ray exposure.

It should be understood that all my storage tubes may be of the electrostatic or of magnetic type. In case electrostatic focusing means 48*a* are used the photocathode should have a slight curvature to improve definition of reproduced image as shown in Fig. 11. The same applies to all other types of photocathodes. In such a case the light reflecting layer 2 which may be of aluminum may serve also as a supporting member. The electron beam from the composite screen 5*a*, 5*b*, or 35 may be intensified by the secondary electron emissive screen such as screen 29*b* shown in Fig. 11. I found however that velocities of secondary electrons emitted from the screen 29*b* vary considerably and they proceed in divergent directions. This leads to deterioration of definition of reproduced image. In my embodiment of the invention I eliminated this defect by using the secondary electron emissive screen 29*b* in the shape of a lens. In this way I may provide suitable potentials so that divergent secondary electrons will be electron-optically focused.

It should be understood that all my storage tubes will be useful in producing images formed by radio isotopes whether they are present in the human body or used in industrial applications. The image formed by radio isotopes such as radio-iodine which emits penetrating gamma radiation cannot be focused on my image storage tube because there are no optical systems, which can focus gamma rays. As a result no image from radio-isotopes distributed in an organ could be obtained. I solved this problem by using in combination with my storage device a pinhole camera as illustrated in Fig. 11. The pinhole camera 107 is made of lead or other material which is able to stop penetrating gamma radiation. The camera 107 is provided with a pinhole opening 108. The storage tube of any type described above is introduced into said lead camera 107 and receives the image passing through the pinhole opening 108. In this way the gamma image may be now focused on the image sensitive screen of the storage tube. The use of a pinhole causes however a great decrease of radiation available for image formation. Therefore my storage devices are of great importance to make such system workable. The weak radio isotope image can be stored in the storage target 41 or 90 and by a long exposure may build up a charge pattern on the storage target which is strong enough to be reproduced as a visible image.

Another embodiment of my invention is shown in Fig. 12. In this modification of my device the perforated storage target is replaced by a target having a continuous imperforated surface of dielectric material such as silica, titanium compounds, BaF_2 or CaF_2. The photocathode may be of any one of the types shown and may be in the form of a composite screen 5*a*, as shown in Fig. 1, or may be in the form of the composite screen as shown

in Fig. 7 or 8, or in the form of a screen 5*b*, as shown in Fig. 2, or screen 35 as shown in Fig. 3 or 26*a* as shown in Fig. 9. The beam of electrons emitted from the photocathode 5*a* and having the pattern of the X-ray or other radiation image is accelerated and is focused by magnetic 48 or electrostatic means 48*a* on the novel storage target 90 which consists of a continuous sheet 90 of a dielectric material such as described above. The impingment of said electron beam causes secondary emission of electrons from said dielectric material which may be higher or lower than unity according to the velocity of the electron beam or potential applied to said storage target. The secondary electrons may be led away by the adjacent mesh screen 91. In some cases it may be preferable to have mesh screen 91 deposited on the surface 91*a* of the target 90 which is facing the composite screen 5*a*. If the electrons are of the velocity at which the secondary electron emission is higher than unity, a positive charge pattern having the pattern of the original image will remain stored in the dielectric target 90. The electron beam from the photocathode could not pass through dielectric target 90 to its opposite side but the charge image can produce by capacitance effect a corresponding charge pattern on the opposite side 91*b* of dielectric target 90. On the side of the dielectric target 91 facing the electron gun 94 is disposed in a close spacing a mesh screen 92. The charge pattern appearing on the surface 91*b* sets up by capacitance effect a similar charge pattern on the mesh screen 92. Screen 92 is irradiated by a beam of electrons 93 from the electron gun 94. The beam 93 after the passage through the opening 95 in the diaphragm 96 is decelerated by decelerating electrodes 97 and is defocused to produce a broad beam 98. The broad electron beam 98 approaches the mesh screen 92 with a very low velocity and is modulated and reflected by the positive electrical pattern on said screen. The reflected broad electron beam has now therefore the imprint of said electrical pattern. The reflected modulated electron beam is striking the fluorescent screen 99 through the light reflecting layer 99*a* such as aluminum and reproduces the visible image which is the replica of the original image. The fluorescent layer 99 is supported by the light transparent diaphragm 96 which should be of preferably light transparent material such as silica or Mylar so that the observer may study the fluorescent image through window 102. The advantage of this novel embodiment resides in the fact that the reading electron beam 98 does not discharge the stored charge image because it does not come in contact with it at all. Therefore the stored image may be read for a desired time without the necessity of maintaining the action of the invisible or visible image forming radiation. As a result my device will protect the living tissues from an excessive radiation. The stored charge image may be removed when desired by producing a broad electron beam of the opposite sign than the stored charge image. Such a broad beam of electrons may be produced by irradiating the photoemissive layer 5 which is inactive at this stage of operation with an extraneous source of light 101 or of ultra-violet. In some cases it may be preferable to provide for this purpose an additional electron gun 94*a* which will produce the erasing electron beam.

Another embodiment of my invention is shown in Fig. 13, which discloses the storage tube with a continuous imperforated target of the type illustrated in Fig. 12, and which may be used for transmission of images. The tube 104 has deflecting means 105 to produce a scanning motion of the fine-focus electron beam 103 across the mesh screen 92. The electron beam 103 after being reflected and modulated by the electrical pattern on the mesh screen 92 returns to the multipliers 106 as beam 103*a*. The multiplied electrons from the multiplier 106 are converted into video signals over a suitable resistance in a manner well known in the art.

Another modification of my invention is shown in Fig. 14, in which the mesh screen 92 is eliminated and the scanning electron beam 103 is allowed to impinge on the target 90. This construction does not permit a long reading of the image as devices shown in Figs. 12 or 13 because the impingement of the electron beam on the target 90 causes neutralization of the positive charges.

Another modification of my invention is shown in Fig. 15 which illustrates the novel image tube 108*a*. The invisible image passes through the face 1 of the tube, which obviously must be of material transparent to the radiation used and may be flat or convex in shape and strikes the composite photocathode 6*a* disposed in the image tube. The composite photocathode 6*a* consists of an invisible radiation transparent, light reflecting layer 2, of a fluorescent layer 3 sensitive to said invisible radiation, of a very thin conducting layer 4*b* and of a photoconductive layer 25. The layer 2 may be of aluminum, gold, silver or platinum and must be very thin in order not to absorb the invisible image. The fluorescent and light transparent conducting layers may be the same as described above.

For neutron images, the fluorescent layer should be activated with elements which have a large cross-section for neutrons, such as boron, lithium, gadolinium or an additional neutron sensitive layer, such as of boron, lithium or gadolinium, should be disposed adjacent to fluorescent layer, as was explained above. In some cases the fluorescent layer should be eliminated and the layer 26*a* may be applied in contact with the photoconductive layer 25 as shown in Fig. 16.

The photoconductive layer 25 may be of CdS, $Sb_2—S_3$, selenium, ZnSe, or PbO. Many sulphides, antimonides, selenides, iodides, arsenides and oxides exhibit photoconductive effect and may be used for the purposes of my invention. The invisible image produces in the fluorescent layer 3 a fluorescent light image having the pattern of said invisible image. The fluorescent image produces within the photoconductive layer a pattern of changes in electrical conductivity and on the surface of said photoconductive layer a pattern of potentials according to the pattern of said fluorescent light image. The photoconductive layer 25 is under the influence of an electrical field produced by an extrinsic source of electrical power, such as battery, which is connected to the conducting layer 4*b*. Under the influence of this electrical field, the electrons and positive holes liberated in the photoconductive layer by the impingement of fluorescent light from the layer 3 move to respective electrodes. Therefore, the pattern of potentials having the pattern of the original X-ray or neutron image appears on the uncovered surface of the photoconductive layer 25. In some cases, better results are obtained by using a pulsating electrical field instead of a battery. In particular, applying a square wave voltage of a low frequency, such as 15–30 cycles per second to the conducting layer 4*b* will markedly improve the sensitivity of the photocathode and will prevent "fatigue" effects.

The uncovered surface of layer 25 is irradiated by a broad beam 93 of electrons from the electron gun 94. The broad electron beam is focused by magnetic or electrostatic fields to a small diameter, so that it will pass through the aperture 95 in the light transparent diaphragm 96, such as of mica, silica or glass. The electron beam 93 after passage through aperture 95 is enlarged by suitable magnetic or electrostatic fields to the size corresponding to the size of the photocathode 6*a*. The electron beam 93 when approaching photocathode, may have velocity of a few hundred volts. It is necessary, however, to use a slow electron beam. Therefore the electron beam 93 is decelerated in front of the photocathode by an additional decelerating electrode 97, which may be in the form of a ring or of a mesh screen. The electron beam approaching the photoconductive layer 25 is modulated by the pattern of potentials on its surfaces. The areas of a higher negative potential will reflect electrons more than areas hav-

ing a lower potential acting as an electron mirror 11A. The reverse situation exists if the X-ray induced conductivity is due to positive holes, because in such a case, the areas of higher positive potential will obviously attract electrons instead of repelling them. The reflected electron beam 93 is therefore modulated by the potential image in the composite photocathode 6*a* and carries the replica of the original image of the examined body.

The reflected electron beam 93 irradiates the fluorescent screen 99, which has electron transparent light reflecting backing 99*a*, such as of aluminum. The impingement of reflected electron beam 93 on fluorescent screen 99 will reproduce the original invisible image as a fluorescent light image. The fluorescent screen 99 should preferably have a very fine grain. ZnO or ZnSCdS phosphor is suitable for this purpose. Better definition will be obtained by evaporated phosphors which have no grain structure and are, therefore, capable of reproducing images of high definition. The fluorescent image can be viewed by the observer through the window 102 and through magnifying optical system. In some cases, the light reflecting layer 99*a* may be omitted and image may be viewed from the uncovered side of the fluorescent screen. In such a case, however, photoconductive layer 25 and the fluorescent screen 99 must be so correlated that a wave length of the fluorescent light should not affect the photoconductive layer 25. For example, antimony trisulphide is not sensitive to blue ilght or selenium may be prepared not to be sensitive to the red light.

A very important feature of my novel image tube is that it can be operated as a storage tube. This means that after the invisible image is formed in the photocathode 6*a* as a pattern of electrical conductivity changes or of electrical potentials, the image forming radiation may be shut off and the image may be read for the desired time. This results in a great reduction of X-ray or neutron exposure of patients, which was one of the primary objectives of my invention. The operation of the image tube 108*a* as a storage tube is essentially the same as described above, except that X-ray or neutron radiation may be stopped after one short exposure. The storage effect of my image tube is due to photoconductive lag observed in insulators, such as selenium, cadmium, sulphide or antimony trisulphide and others when the incident light is of a low intensity. Such conditions prevail in medical fluoroscopy where the brightness of fluorescent light image produced in layer 3 by X-ray or neutron image is in the range of 0.01–0.001 footcandle. The photoconductive lag means that conductivity pattern within the layer 25 and potential pattern on the uncovered surface of said photoconductive layer persists for many seconds. During all this time, the electron beam 93 can be modulated by said conductivity or potential pattern and will reproduce visible image corresponding to the original X-ray or neutron image in the fluorescent screen 99. The photoconductive lag may be prolonged by refrigerating the photoconductive layer 25 of the photocathode, or by addition of suitable impurities, such as Cu when using CdS for a photoconductive layer. It should be added that the tube 108*a* shown in Fig. 15 may be provided with a composite screen 5*a* for receiving an image and converting said image into a beam of free electrons. The beam of free electrons will in turn act on the composite screen 6*a* to produce a stored potential image as was explained above.

Another important advantage of my photoconductive tube resides in the efficiency of the photoconductive layer as compared with the previously used photoemissive layer. Whereas the best photoemissive materials have quantum efficiency of the order of 3 to 5%, the photoconductive layer 25 has quantum efficiency close to unity or even exceeding unity. The efficiency of photoconductive layer 25 can also be increased by providing a strong electrical field across it, which serves to move liberated electrons and positive holes across said layer.

A great problem in quality of images produced by my devices is the reproduction of contrast values which means reproduction of half-tones. I found that I may improve the contrast and in addition amplify arbitrarily the contrast of reproduced images by using in front of the photocathode of any type described above a mesh screen 24 as shown in Fig. 13. The mesh screen 24 is connected to the source of an extraneous electrical power such as battery and may be supplied with various necessary potentials. By providing the mesh screen 24 with a potential which will cause cut-off of electrons of certain predetermined velocity we may vary arbitrarily the contrast of reproduced image. The mesh screen 24 has wide mesh openings in order not to cause the loss of a large percentage of electron beam. It should be understood that the use of contrast regulating mesh screen 24 is intended for all embodiments of my invention.

It should be understood that the image reproducing screen 44 in all types of tubes described may be of material capable of the storage of the image. Screen 44 may be of persistent phosphors such as fluorides which have a long after-glow. In some cases screen 44 may be of a scotophore material which means of material changing its color under the influence of electron irradiation. There are many scotophores known in the art such as halides; especially useful is potassium chloride. In case a scotophore type of screen is used means must be provided to return this screen to the original condition after the image has been read. For this purpose we may use either heating of said screen or we may use a strong beam of electrons which may be supplied by the photoemissive layer of the composite screen irradiated by a strong extraneous source of light. It should be understood that the image appearing in the reproducing screen of fluorescent type or of tenebrescent type or other types may be photographed or recorded on a suitable surface to provide a permanent record thereof.

It should be understood that all modifications of my device are suitable also for the storage of images produced by ultra-violet radiation. In such a case the photocathode may be of composite type such as shown in Fig. 1. The fluorescent layer will be of material sensitive to particular wave-length of ultra-violet radiation used. For example, phosphors such as calcium phosphate, calcium silicate or barium silicate with suitable activators are sensitive to ultra-violet rays of 3000 A. In case ultra-violet radiation is of a shorter wave-length such as 1000–3000 A. the photocathode may be of a single layer type using potassium, sodium salicylate or silver chloride as a photoemissive layer.

My invention in all its modifications may be also used for the storage of infra-red images. In such case the photocathode may be of composite type as shown in Fig. 1. The fluorescent layer may be of one of infra-red sensitive phosphors such as alkaline earth sulphides or selenides activated by cerium, samarium or europium. In case infrared radiation is of a longer wave-length such as 2–20 microns we may use a single layer photocathode of material such as PbS, tellurides, antimonides or of barium titanate or other titanium compounds.

It may be added that the preferable way of dissolving Mylar is to heat it to temperature of 250° C. at which it becomes liquid. When it is in a liquid condition we may add to it a desired quantity of a phosphor. After a thorough mixing we let the solution cool off and solidify again. In this way a self-supporting layer of fluorescent material and a light transparent separating layer of Mylar of the desired thickness such as 1–20 microns are produced. On this composite screen we may deposit a light transparent conducting layer and a photoelectric layer such as a photoemissive layer, as described above.

In some cases the fluorescent layer and light transparent conductive layer may be eliminated and the neutron reactive layer or the X-ray reactive layer 26*a* may be applied in direct contact with the side of the photoconductive

layer 25 which is facing the image. This arrangement is shown in Fig. 16 and is especially suited for very penetrating X-rays or gamma rays. The materials for neutron or X-ray reactive layer were described above.

In some cases the image tube shown in Fig. 15 may be simplified by using as a photocathode instead of a composite screen provided with a fluorescent layer, a screen of material such as cadmium, sulphide or lead oxide which when irradiated by X-rays or neutrons change their electrical conductivity. The remaining part of the tube may be the same as described above and shown in Fig. 15.

The layer of CdS or of PbO may be preferably deposited on a conducting layer of material transparent to the image forming radiation such as gold, platinum or tungsten. A source of electrical potential should be connected to said conducting layer to provide the bias potential.

It should be understood that all tubes described above may be adapted to transmit the images instead of reproducing them in the same tube. Such adaptation of one of the embodiments of my invention to serve as a pick-up tube, which means a transmitting tube, will be shown in Fig. 17. The tube 109 is characterized by the photocathode 110 comprising a dielectric layer of material showing changes of electrical conductivity when irradiated by an invisible radiation and a conducting layer 112 transparent to the image forming radiation. Layer 111 may be of CdS, PbO, PbS or PbSe. Layer 112 may be of gold, platinum or silver. A source of direct current such as battery or preferably of a low frequency alternating current should preferably be connected to layer 112 to provide the biasing potential.

The X-ray or other invisible radiation is converted in the layer 112 into a pattern of electrical conductivity changes. The photocathode 110 is scanned by the slow electron beam 113 from the electron gun 94. The electron is decelerated in front of the photocathode 110 by the decelerating electrode 114 to almost zero velocity.

The impingement of the scanning electron beam on the layer 111 produces electrical impulses at the conducting layer 112 which may be converted over a suitable resistance into video signals. The returning electron beam 113*a* is also modulated by the pattern of conductivity changes in the photocathode 110 and therefore carries also video information. The returning beam 113*a* may be directed to multipliers 115 and after electron multiplication may be converted into video signals. The focusing coils 116 and deflecting coils 117 are not illustrated in detail as they are well known in the art.

Tube 109 may also serve as a storage tube by providing in front of the photocathode 110 a mesh screen 110*a* which will serve as an electron mirror and will reflect the scanning electron beam 113. In the first stage of operation of the tube the scanning electron 113 will be allowed to pass through the mesh screen 110*a* by a suitable choice of potentials. The electron beam 113 will thus deposit electrons on the dielectric layer 111. After the layer 111 was subjected to the image forming radiation, the potential pattern will appear on the mesh screen 110*a* by a capacitance effect from the layer 111. This potential pattern will now serve to reflect and modulate the scanning electron beam 113. In this phase of operation the potential of the mesh screen is so adjusted so that the scanning electron 113 cannot pass through it but is reflected instead.

It should be understood that all embodiments of my invention can be further improved to make them able to discriminate between X-ray or gamma images and images produced by atomic particles. This is a very important feature of my invention as many sources of atomic particles are at the same time a source of gamma radiation. I obtained the differential response of my devices to one type of radiation only by providing all my modifications of invention with a mesh screen of conducting material 24 such as shown in Fig. 13. The screen 24 should be of material not emitting secondary electrons. The mesh screen 24 is connected to the source of electrical potential. By applying proper potential to said screen 24, the electrons caused by impingement of gamma rays and which have a relatively low velocity will be cut-off by said mesh screen. On the other hand the electrons or other secondary atomic particles which are produced by impingement of the primary image forming atomic particles and which are of relatively high velocity will be able to pass through the mesh screen. In this way discrimination between gamma images and atomic particles image is accomplished.

It will thus be seen that there is provided a device in which the several objects of this invention are achieved and which is well adapted to meet the conditions of practical use.

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 tube having in combination a photocathode comprising a continuous photoelectric layer for receiving an image and converting said image into an emitted beam of electrons, said photoelectric layer comprising an element of the group antimony and bismuth, an apertured member having a planar shape disposed in the path of said beam and transmitting particles of said beam emitted by said photocathode and a screen comprising an electron pervious light reflecting layer and luminescent means for receiving said transmitted electrons.

2. A device as defined in claim 1, in which said apertured member is a mesh screen of conducting material and is connected to a source of electrical potential, said source producing only a unidirectional current.

3. A vacuum tube having luminescent means and photoelectric means and light transparent separating means comprising a plastic material, all aforesaid means forming together a composite screen.

4. A vacuum tube having a composite screen comprising luminescent means and photoelectric means and light transparent separating means comprising a polyester.

5. A vacuum tube having in combination luminescent means for producing a luminescent image, a photocathode comprising a continuous photoelectric layer for receiving said luminescent image and converting said image into an emitted beam of electrons forming an electron image, said photoelectric layer comprising an element of the group antimony and bismuth, a mesh screen connected to a source of electrical potential disposed in the path of said beam and controlling transmission of electron of said beam emitted by said photocathode and a screen comprising an electron pervious light reflecting layer and second luminescent means producing a second luminescent image corresponding to said electron image.

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