United States Patent [19]

Sheldon

[11] **3,749,920**

[45] **July 31, 1973**

[54] **SYSTEM FOR X-RAY IMAGE INTENSIFICATION**

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[52] **U.S. Cl.** ..... **250/213 VT,** 313/108

[51] **Int. Cl.** **H01j 1/62,** H01j 31/50, H01j 39/12

[58] **Field of Search** ..... 250/213 VT, 207; 313/103, 108 R

[56] **References Cited**

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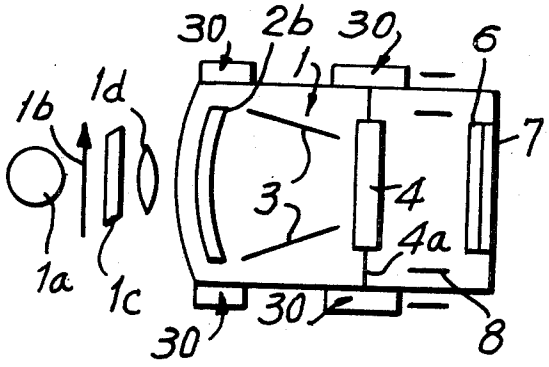
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Primary Examiner—William F. Lindquist
Assistant Examiner—T. N. Grigsby
Attorney—Laforest S. Saulsbury et al.

[57] **ABSTRACT**

This invention relates to a system of X-ray image intensification characterized by the use of an image intensifier provided with a novel electron multiplying membrane which produces a very high intensification of the original image and which has the construction preventing the back-scatter of reflected light. This system permits to eliminate or to reduce the use of electron-optical demagnification used in present X-ray image intensifiers, and to improve thereby contrast and resolution of intensified X-ray images.

16 Claims, 16 Drawing Figures



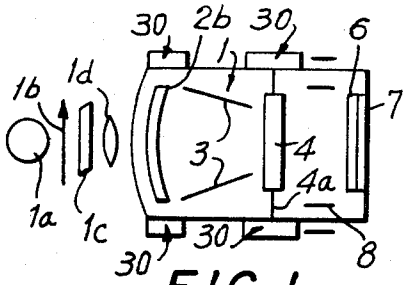


FIG. 1

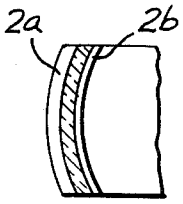


FIG. 1A

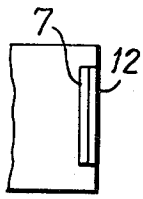


FIG. 1B

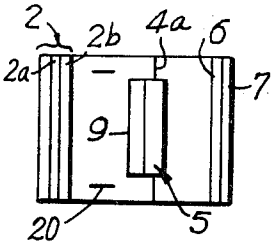


FIG. 1C

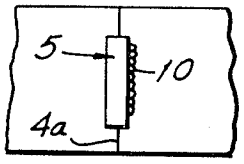


FIG. 1a

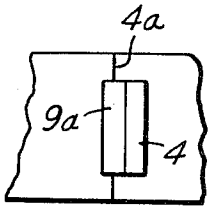


FIG. 1b

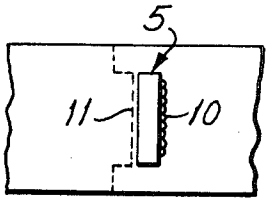


FIG. 1c

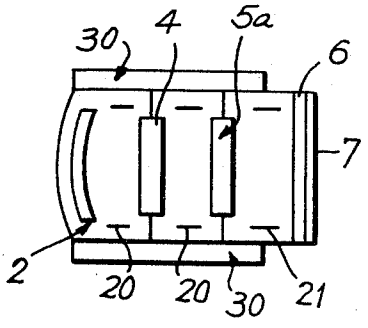


FIG. 2

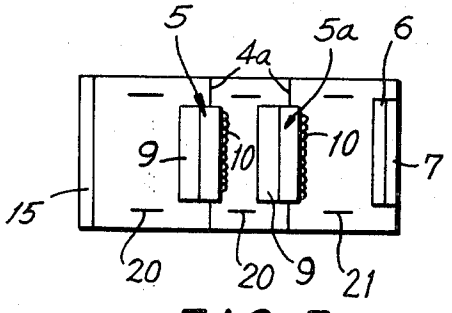


FIG. 3

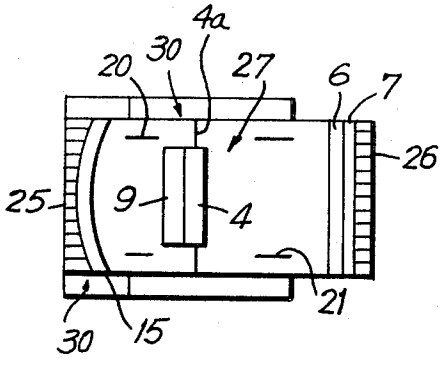


FIG. 3a

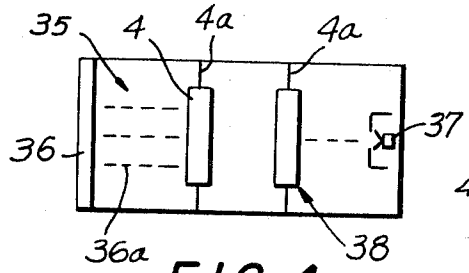


FIG. 4

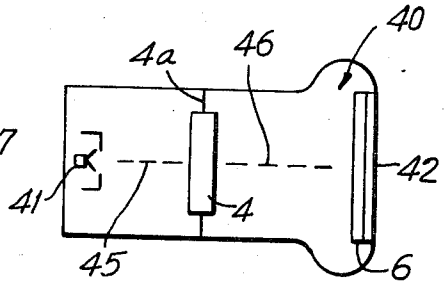


FIG. 5

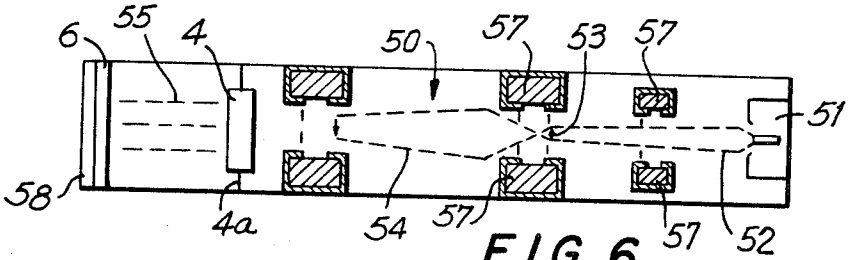


FIG. 6

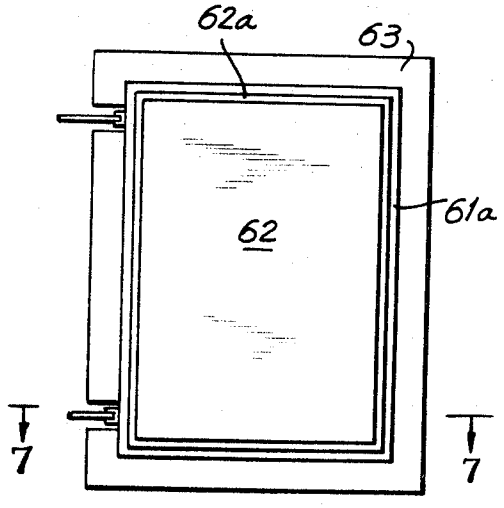


FIG. 7a

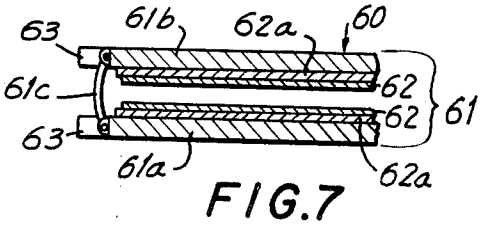


FIG. 7

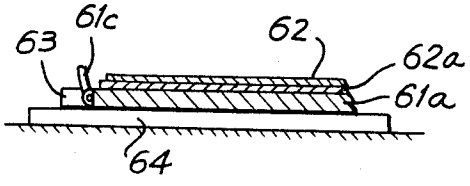


FIG. 7b

SYSTEM FOR X-RAY IMAGE INTENSIFICATION

This invention relates to a novel system of X-ray image intensification for various radiations such as X-rays, gamma rays, neutrons and other atomic particles, and also for light images of visible and invisible spectrum and has common subject matter with my Ser. No. 584,318 filed Sept. 22, 1966; with U.S. Pat. No. 3,499,107 filed Nov. 28, 1956; with U.S. Pat. No. 3,021,834 filed Nov. 28, 1956 and with U.S. Pat. No. 2,877,368 filed March 11, 1954.

The invention comprises the use of a novel image intensifier provided with an electron multiplying membrane which absorbs all primary electrons in the range of 5–25KV and allows at the same time escape of substantially all secondary electrons produced in said membrane by the primary electrons. This electron multiplying membrane uses p-type silicon which was found to have this unique capability. The use of such membrane in image intensifying tubes results in a great intensification of the original images such as by a factor of 100–1,000. In addition, this electron multiplying device produces images of much better contrast and detail because none of the primary electrons are transmitted through the membrane and cannot therefore damage the contrast and detail of the final image, as it was the case in the devices of the prior art.

It was found that signal to noise ratio in performance of such intensifiers is greatly improved by providing on the surface of said membrane which receives the beam of primary electrons light absorbing means which prevent the back scatter of light reflected by said membrane.

In addition it was found that the electron multiplying power of such silicon membrane is greatly improved by providing a very thin layer of caesium on its surface.

In addition it was found that the intensification power of image intensifiers provided with such electron multiplying membrane can be greatly increased by using two or more of such membranes spaced apart from each other, whereby the second membrane intensified the electron beam produced by the first membrane.

IN THE DRAWINGS

The invention will be better undersood when taken in combination with the accompanying drawings:

FIG. 1 represents an X-ray image intensification system.

FIG. 1A represents modification in which the luminescent layer is mounted on the outside surface of the endwall of vacuum tube.

FIG. 1B represents the modification in which the light transparent and electrically conducting layer is provided in front of luminescent means.

FIG. 1C shows X-ray image intensifier in which the luminescent layer is mounted inside the vacuum tube.

FIG. 1*a* shows a modification of novel electron multiplying membrane.

FIGS. 1*b* and 1*c* show supporting means for electron multiplying membranes.

FIG. 2 shows cascade type of image intensifier.

FIG. 3 shows light sensitive image intensifier with electron multiplying membrane.

FIG. 3*a* shows modification of embodiment of FIG. 3 which is provided with fiberoptic endwalls.

FIG. 4 shows television pick-up tube with electron multiplying membrane.

FIG. 5 shows kinescope tube with electron multiplying membrane.

FIG. 6 shows electron microscope with electron multiplying membrane.

FIG. 7 shows X-ray intensifying cassette with cooling means.

FIG. 7*a* and 7*b* show modifications of X-ray cassette.

FIG. 1 shows the novel X-ray image intensifying system. The X-ray source 1*a* produces the image of the examined object 1*b*. The X-ray image is converted by X-ray sensitive luminescent means 1*c* into a luminescent image. The luminescent image is projected by optical means 1*d* onto photocathode which comprises photoemissive means 2*b*. The photocathode converts luminescent X-ray image into a beam of primary electrons which has the pattern of the original X-ray image. The photoemissive means may comprise caesium with antimony or a mixture of caesium with sodium or with potassium with antimony.

It should be understood that in some applications instead of using the luminescent screen 1*c* mounted outside and spaced apart from the vacuum tube 1, a composite X-ray sensitive screen 2 may be used also. This construction is shown in FIG. 1C. The X-ray sensitive screen 2 comprises the first luminescent means 2*a* and photoemissive means 2*b*. It should be understood that other X-ray reactive means may be used instead of the above described means 2. The luminescent means 2*a* may be in some applications mounted also on the external surface of the endwall of the vacuum tube 1. FIG. 1A shows the construction in which luminescent means 2*a* are mounted on the external surface of the endwall. It should be understood that the above described modifications of the luminescent means 2*a* apply to all embodiments of the invention described or illustrated in this specification.

The beam of primary electrons produced by photoemissive means 2*b* is focused by electrodes 3. The electrodes 3 may be preferably of the demagnifying type for said electron beam and may be of electrostatic type or of magnetic type such as a permanent magnet or an electro-magnet, or in the form of evaporated magnetic electrodes on the inside surface of side-walls. The primary electron beam is accelerated to the velocity between 9KV and 25KV and impinges on the electron multiplying membrane 4, which comprises p-type silicon. It was found that such membrane if made of the thickness not exceeding 20 microns, has the unique property of absorbing substantially all primary electrons and allowing at the same time substantially all secondary electrons to escape from it through the side opposite to the side on which the primary electron beam has impinged. More specifically, it was now found that it is critical for p-type silicon membrane to be of the thickness larger than 1 micron and not exceeding 20 microns. The membrane 4 because of its unique property described above has an electron multiplying effect by a factor of 50–200, which is greatly superior to any other secondary electron emitters. It is possible therefore by the use of one electron multiplying membrane 4 to produce a great intensification of the image. This permits the construction of image-intensifiers of a small size and of great efficiency in spite of said small size.

The intensified secondary electron beam has the pattern of the original X-ray image and is now focused or projected on the second luminescent means 7 to pro-

duce a visible image with any desired intensification which may be as high as 10^5. The luminescent means **7** may be of conventional construction or may be of evaporated phosphors because of this high intensification factor. Luminescent means **7** may have a backing of light reflecting material such as aluminum **6.** It should be understood that in some applications the layer **6** may be omitted and the electrical terminal is provided in the form of light transparent and electrically conducting layer **12** mounted between the inner surface of the endwall of vacuum tube **1** and the luminescent means **7,** as it is illustrated in FIG. **1B.** The layer **12** may be of tin oxide, or of evaporated gold or silver or platinum. In this embodiment of invention the membrane **4** and its supporting member **4***a* must occlude all of the inner diameter of the vacuum tube **1** to prevent back-scatter light from the luminescent means **7** to reach the photoemissive layer **2***b*. In addition, the supporting member **4***a* must be light opaque for this purpose. Also light opaque means must be provided on the inner surface of walls of the tube to prevent such back-scattered light from traveling along the side-walls to the photoemissive layer **2***b*.

The focusing of the secondary electron image on the luminescent means **7** may be accomplished by electrostatic means **8** or by magnetic or by electromagnetic means. In some embodiments of the invention, it is preferable to use the proximity focusing. In such case the spacing between the membrane **4** and the luminescent means **7** must be reduced so that it does not exceed 1–2mm. It should be understood that the use of proximity focusing applies to all embodiments of the invention.

It was found unexpectedly that a great improvement of electron multiplying capability of silicon membrane **4** can be obtained by depositing on the surface of said membrane an extremely thin layer **10** of caesium or other alkali metal such as sodium or potassium of the thickness not exceeding **160A**. This important feature of the invention is illustrated in FIG. **1***a* or in FIG. **1***c*. It should be understood that the use of silicon membrane **5** with caesium or other alkali metal coating applies to all embodiments of this invention.

The X-ray image intensifiers using the above construction comprising electron multiplying membrane **4** or **5** are greatly superior to the presently used X-ray image intensifiers. The standard X-ray image intensifiers must use for the purpose of intensification an electron-optical demagnification of the electron beam by a factor of 8–10. This excessive demagnification causes a great loss of resolution and contrast in the final image.

In the present construction the electron-optical demagnification can be eliminated completely or if used at all it may be reduced to the acceptable factor of about 3 to 4. As explained above, this reduction of electron-optical demagnification represents a basic improvement in the art of X-ray image intensifiers.

Furthermore, the use of electron multiplying membrane **4** or **5** or their modifications permits elimination of electron focusing electrodes and the use of proximity focusing instead. This makes it possible to construct a very compact X-ray image intensifier which in addition may have now planar endwalls which will improve the resolution of images because chromatic aberration of electron image is markedly improved. This embodiement of invention is illustrated in FIG. **1C**. It should be understood that this improvement applies to all embodiments of invention.

Another important improvement in the image intensifiers resides in the use of **2** or more membranes **4** or **5** or their modifications in the same vacuum tube in a spaced apart relationship for producing a cascade type of intensification. This construction is found in FIG. **2.** The secondary electrons from membrane **4** or **5** are accelerated by the electrostatic or magnetic means **20** or **21,** and impinge on the membrane **4** or **5***a* and produce a new multiplication of electrons which brings about a very high intensification of the original image. It should be understood that the cascade construction applies to all embodiments of invention.

Instead of mounting the membranes in the same vacuum tube as was described above, it is also possible to use two separate vacuum tubes in a tandem arrangement. Each vacuum tube is provided with one membrane **4** or **5** or their modifications only. Two such vacuum tubes are brought into an abutting back to back relationship. This is possible if the abutting endwalls of both tubes have fiber-optic construction. Such construction and the transfer of a fluorescent image from one tube to the photoelectric means in the second tube is described in the detail in my U.S. Pat. Nos. 2,877,368 3,021,834 and 3,499,107 which are to be incorporated by reference.

It should be understood that this invention is not limited to X-rays or neutron images but it applies as well to all light images. The term "light" embraces the visible light and the invisible light such as infrared and ultraviolet. This modification of the invention is shown in FIG. **3** which illustrates light sensitive photoemissive photocathode **15** instead of X-ray sensitive means **2.** All embodiments and modifications described for X-ray image intensifiers apply to the light sensitive image intensifiers as well. FIG. **31** shows the use of endwalls **25**a and **26** in the intensifier tube **27** which are of fiberoptic construction. It should be understood that fiberoptic construction of endwalls of vacuum tubes applies to all embodiments and modifications of tubes described in this specification.

A great improvement of the signal to noise ratio in performance of such image intensifiers provided with an electron multiplying membrane **4** or **5** or their modifications was accomplished by depositing on the surface of such membrane which faces the photoemissive means **2***b* or **15** special light absorbing, non-reflecting means **9.** It was found that such construction prevents the luminescent light from luminescent means **2***a* which was transmitted through the semi-transparent photoemissive layer **2***b* from being reflected by the highly reflecting surface of silicon membrane **4** or **5** or their modifications back to the photoemissive layer **2***b* or **15,** whereby the contrast and resolution of the primary electron image is damaged. An evaporated layer of chromium oxide or aluminum oxide or a layer of carbon black may be used to produce such light absorbing means **9** and such means **9** must be of the thickness which being light opaque will permit the primary electron beams from the layer **2***b* to be transmitted without losses. In any event, the thickness of such layer must be larger than **100A** in order to be effective for the above purpose. It should be understood that this improvement applies to all embodiments of this invention.

It was furthermore found that a great loss of signal to noise ratio in performance of these novel intensifiers

occurs because of high thermal electrons emission from silicon membrane **4** or **5** or their modifications at room temperature. It was found that the use of the coating **10** of caesium or other alkali metals such as sodium or potassium or lithium described above will improve markedly the signal to noise ratio because it will reduce the emission of thermal electrons. It is believed that such reduction of thermal electrons is due to the fact that they have a much lower velocity than the secondary electrons emitted by said membranes and therefore they are mostly arrested by said coating **10** whereas the secondary electron will be able to penetrate it. It is critical therefore, that the thickness of coating **10** should not exceed **150A**. It was found that not all thermal electrons can be arrested by the coating layer **10** without causing large losses of the secondary electrons. In some cases it is necessary therefore to provide in addition cooling means **30** for the membrane **4** or **5** or their modifications. The cooling to temperature at least 80° C below zero and in some cases to about the temperature of liquid nitrogen (77° K) is sufficient for this purpose and may be accomplished by the cooling devices of thermal-electric type or of Dewar type.

In the X-ray image intensifiers which are provided with luminescent means **2***a* of CsI or NaI, it was found that the use of cooling means applied to said luminescent means increased the quantum efficiency of such phosphors by factor as high as **5** to **10.** The cooling to the temperature of at least −80° C and preferably to −180° C is sufficient for this purpose. The cooling means **30** may be extended to cover the region of luminescent means **2***a* or separate cooling means may be provided for said luminescent means and the electron multiplying membrane. In conclusion the use of cooling means **30** was found to improve the operating performance of all such image intensifiers and represents an important feature of this invention.

The invention is not limited to vacuum tubes of image type but is intended also for television pick-up tubes and kinescopes as well. FIG. **4** illustrates the novel television pick-up tube **35** which comprises the photocathode **36,** image intensifying membrane **4** or **5** or any of their modifications, storage target **38** and electron gun **37.** It should be understood that the invention applies to many types of television pick-up tubes. Image Vidicons, Image Orthicons or Image Dissectors may be constructed with the membrane **4** or **5** or their modifications. The Image Storage target **38** may be composite screen comprising luminescent means and photoconductive means, or it may be an array of p-n or p-i-n diodes, or semiconducting glass or a thin layer of MgO or a screen of KCl. The electron gun **37** may be in some cases replaced by means which produce a scanning light beam and are mounted outside of said vacuum tube **35.** In operations of such tubes **35** the photoelectron beam **36a** impinges on the membrane **4** or **5** and is converted into a secondary electron beam of much greater intensity as was explained above. The secondary electron beam impinges on the storage target **38** and is converted into a stored charge image. The stored charge image is scanned by electron beam from the electron gun **37** which produces video signals from said tubes.

FIG. **5** illustrates a novel kinescope provided with an electron multiplying membrane **4** or **5** or their modifications. The kinescope **40** comprises a source electron beam such as single or plural electron gun **41** or a matrix of electron emitters. The electron beam **45** from gun **41** impinges on the electron multiplying membrane **4** or **5** or their modifications. It is intensified as it was explained above, and the exiting intensified secondary electron beam **46** irradiates the phosphor screen **42** and produces an image of a high brightness.

FIG. **6** illustrates novel electron microscope **50** provided with the image intensifying membrane **4** or **5** or their modifications. The electron microscope **50** comprises a source of electrons **51** which produces the beam of electrons **52** which is focused by electron-optical lenses **57.** The beam **52** impinges on the examined specimen **53** and the transmitted electron beam **54** carries the image of said specimen. The beam **54** impinges on the image intensifying membrane **4** or **5** or their modifications and is amplified as was explained above. The amplified secondary electron beam **55** can be used to produce a luminescent image on the phosphor screen **58** or to produce a photographic image or to be converted into video signals.

In some applications the membranes **4** or **5** or their modifications may be ruggedized by providing an additional supporting member **9***a* such as a continuous film of aluminum oxide or silicon oxide as it is shown in FIG. **1***b*. Such supporting layer **9**a may be of the thickness of 500–1,000A and will transmit well the primary electrons which as was explained above have the velocity of 5–20KV. Instead of a continuous layer of Al_2O_3 or SiO_2, a wide mesh screen may be used in some applications as it is shown in FIG. **1***c*, see part **11.**

It may be added that in some applications instead of p-type silicon other materials may be used for the membrane **4** or **5** or their modifications. Such materials will be preferably of compounds of III-V group such as GaAs or GaP.

It should be understood that in all embodiments of invention the silicon membrane is preferably connected to the source of electrical potential directly, which means that it does not require any base layer of electrically conducting material to be connected to said source of electrical potential.

It should be understood that in all embodiments of invention the focusing electrodes may be in the form of magnetic electrodes evaporated on the inside surface of side-walls of image intensifier tube and connected to a source of electrical potential. FIG. **7** shows novel X-ray intensifying portable cassette **60.** The cassette **60** comprises a hinged-type frame **61** which consists of base **61***a* and of lid **61***b* which are united together by means of a hinge **61***c* as it is well known in the art. The X-ray intensifying cassette is provided with one or two evaporated layers of CsI **62** which are of the thickness of 0.1mm to 0.25mm with activators such as Na or Tl. It should be understood that layers of CsI **62** may be also used without activators. They are mounted on the inside surface of the lid **61***b* and on the inside surface of the base **61***a*. They may be also evaporated directly on said inside surface of lid **61***b* and of the base **61***a*. In such case both the lid **61***b* and base **61***a* must be of material resistant to the temperature of 400° C. It was found that it is preferable in some cases to evaporate CsI layers on a supporting member which can be mounted inside of the cassette **60.** Such supporting member must be of material which is resistant to the temperature of at least 400° C, for example aluminum will be suitable material. In some cases light absorbing layer of a heat-resistant material such as of magnesium

oxide or of titanium oxide may be interposed between the supporting member **62***a* described above and CsI layer **62**.

It was found that luminescent materials such as CsI when subjected to the temperature lower than 100° C below zero exhibit a great improvement in their luminescent emission in response to X-rays, gamma rays or neutrons. This improvement of luminescent emission may be by a factor of 500 percent or more. The novel X-ray intensifying cassette **60** is provided with cooling means **63** to obtain the above described improvement. The cooling means may be of thermo-electric type or of Dewar type using e.g. containers with liquid nitrogen. The cooling means **63** may be mounted on the base **61***a* and may surround the circumference of the base or may be attached to its major external surface as it is shown in FIGS. **7***a* and **7***b* respectively. The cooling means **63** if they are of thermo-electric type are connected to an outside source of electrical power. In some cases cooling means **63** may be also mounted to surround the circumference of the lid **61***b*.

It should be understood that in some applications instead of CsI a layer of NaI may be used instead or in combination with CsI. The layer of NaI may be provided with activators such as K or Tl.

In another embodiment of invention cooling means **63** may be mounted adjacent to the major external surface of the base **61***a* but in spaced apart relationship and may be either attached to the edge of the cassette **60** or may have a separate supporting member **64**.

It should be understood that the use of cooling means for evaporated layer of luminescent CsI applies not only to portable X-ray cassettes but is intended also for stationary X-ray film holders as well. For example screens of evaporated CsI with cooling means **63** may be used in horizontal or vertical systems which use a continuous X-ray film delivery such as The Picker Rapido System or the Picker Automatic Chestfilmer described in Radiology Vol. 100 No. 2, Aug., 1971.

The layer of CsI in all embodiments of invention should have the thickness not exceeding 0.25mm.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appended claims.

What I claim is:

1. A device for X-ray image intensification comprising in combination an X-ray source producing an X-ray image of the examined object, luminescent means for receiving said X-ray image and converting said image into a luminescent image, an image intensifier tube for receiving said luminescent image and converting said luminescent image into a primary electron beam having the pattern of said radiation, an imperforate membrane comprising silicon of the thickness larger than 1 micron and mounted in the path of said primary beam for receiving said electron beam and intensifying said electron beam, said primary beam impinging on one side of said membrane, said membrane emitting a secondary intensified electron beam from the side opposite to the side impinged by said primary beam, and means for receiving said intensified secondary electron beam and reproducing said X-ray image.

2. A device as defined in claim **1** in which said membrane is constituted substantially of p-type silicon.

3. A device as defined in claim **1** in which light absorbing means are mounted on the side of said membrane which receives said primary beam of electrons, said means preventing the reflection of light by said membrane.

4. A device as defined in claim **1** in which coating means are deposited on the side of said membrane which emits said secondary electron beam, said coating means comprising an alkali metal of the group consisting of caesium, sodium, potassium and lithium, said coating furthermore not exceeding the thickness of 150A.

5. A device as defined in claim **1** in which said membrane is connected directly to the source of electrical potential.

6. A device as defined in claim **1** which comprises means for cooling said membrane to the temperature lower than 80° C below zero.

7. A device as defined in claim **1** in which said membrane is provided with a supporting member mounted on the side of said membrane which receives said primary electron beam.

8. A device as defined in claim **3** in which said membrane is constituted substantially of p-type silicon.

9. A device as defined in claim **4** in which coating means are deposited on the side of said membrane which emits said secondary electron beam, said coating means comprising an alkali metal of the group consisting of caesium, sodium, potassium and lithium, said coating not exceeding the thickness of 150A.

10. A device as defined in claim **3** which comprises means for cooling said membrane to the temperature lower than 80° C below zero.

11. A device as defined in claim **1** which comprises means for cooling said luminescent means to the temperature lower than 80° C below zero.

12. An image intensifier vacuum tube comprising photoemissive means for receiving a beam of radiation carrying an image and converting said beam into a primary electron beam having the pattern of said radiation, an imperforate membrane comprising silicon of the thickness larger than one micron and mounted in the path of said primary beam for receiving said electron beam and intensifying said electron beam, said primary beam impinging on one side of said membrane, said membrane emitting a secondary intensified electron beam from the side opposite to the side impinged by said primary electron beam and which secondary beam has the pattern corresponding to said primary beam, and means for receiving and utilizing said intensified secondary electron beam.

13. A device as defined in claim **12** in which said membrane is constituted substantially of p-type silicon.

14. A device as defined in claim **12** in which light absorbing means are mounted on the side of said membrane which receives said primary beam of electrons, and said means preventing the reflection of light by said membrane.

15. A device as defined in claim **12** in which coating means are deposited on the side of said membrane which emits said secondary electron beam, said coating means comprising an alkali metal of the group consisting of caesium, sodium, potassium and lithium, said coating not exceeding the thickness of 150A.

16. A device as defined in claim **12** which comprises means for cooling said membrane to the temperature lower than 80° C below zero.

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