Sept. 28, 1954 E. E. SHELDON 2,690,516

METHOD AND DEVICE OF PRODUCING NEUTRON IMAGES

Original Filed March 9, 1948 2 Sheets-Sheet 1

FIG. 1

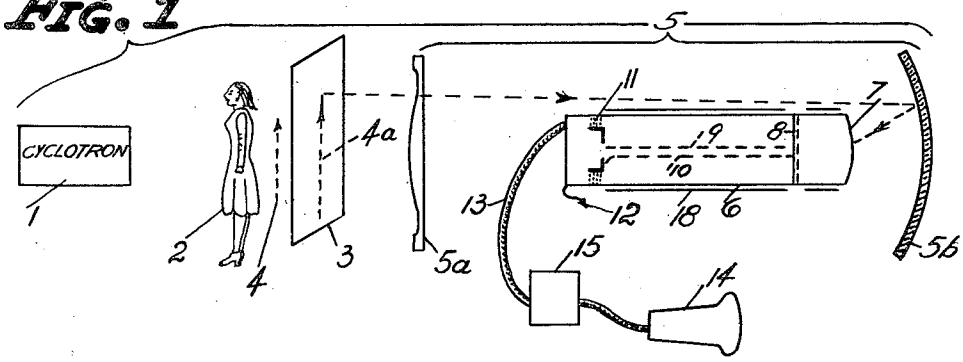


FIG. 2

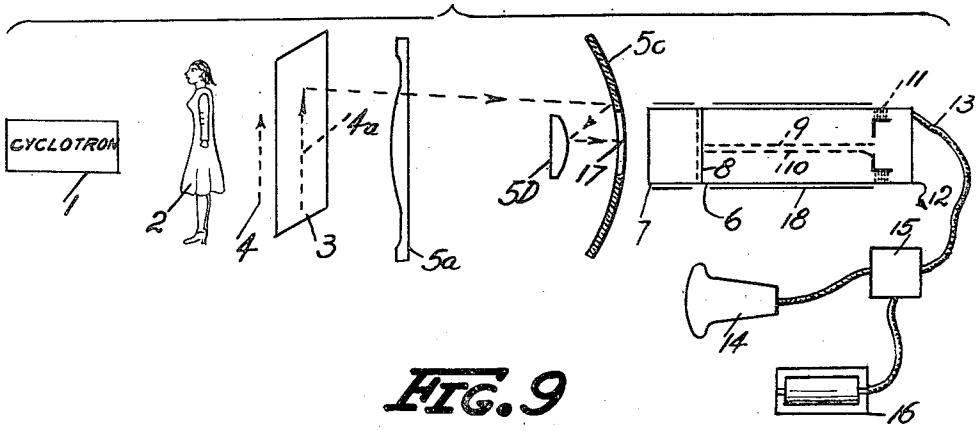


FIG. 9

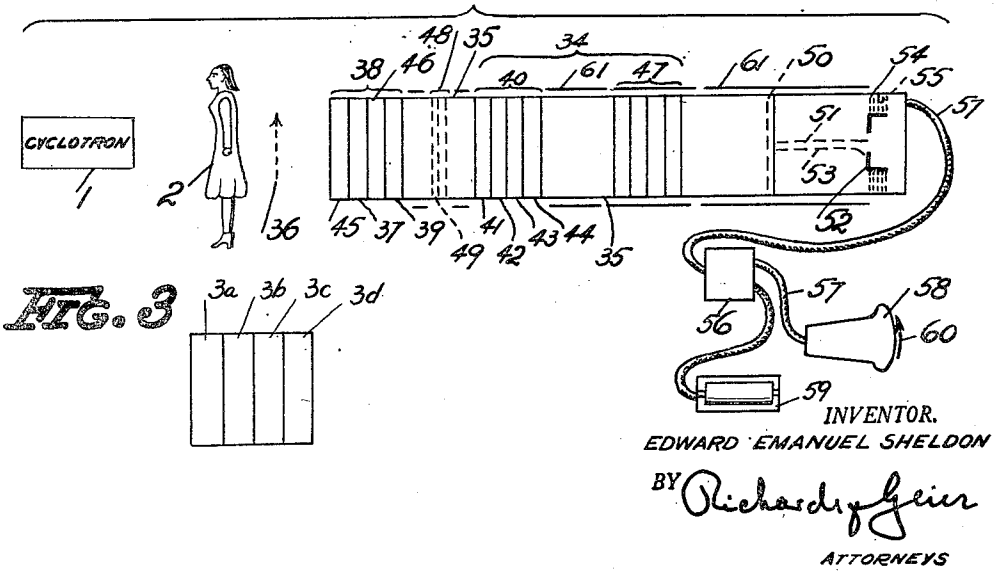


FIG. 3

INVENTOR.
EDWARD EMANUEL SHELDON
BY Richards & Geier
ATTORNEYS

Sept. 28, 1954 E. E. SHELDON 2,690,516

METHOD AND DEVICE OF PRODUCING NEUTRON IMAGES

Original Filed March 9, 1948 2 Sheets-Sheet 2

FIG. 4

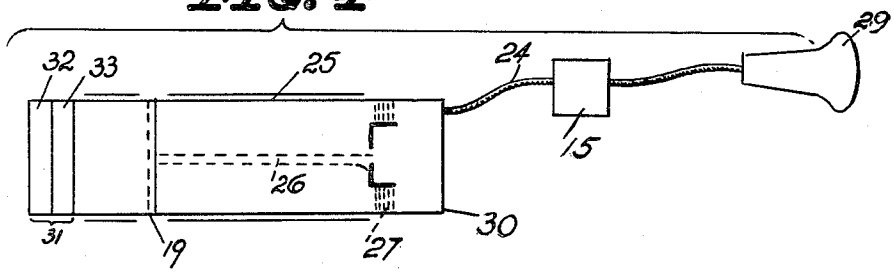


FIG. 5

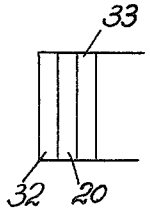


FIG. 6

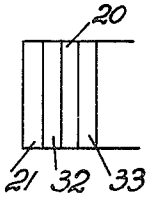


FIG. 7

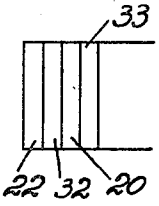


FIG. 8

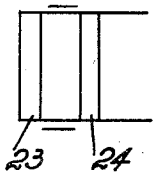


FIG. 10

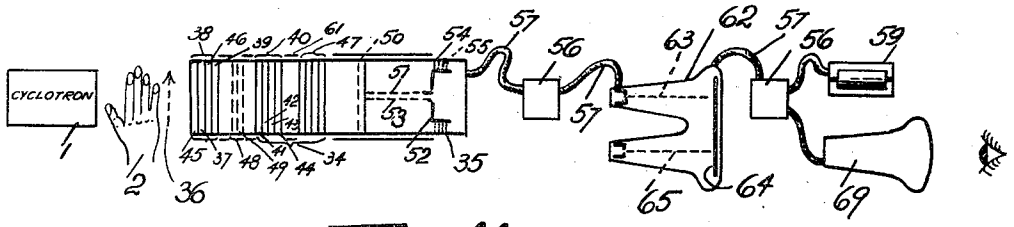
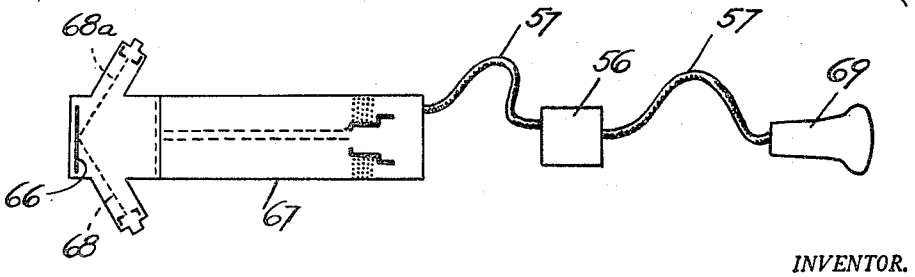


FIG. 11



INVENTOR.
EDWARD EMANUEL SHELDON
BY Richards & Geier
ATTORNEYS

Patented Sept. 28, 1954

2,690,516

UNITED STATES PATENT OFFICE

2,690,516

METHOD AND DEVICE FOR PRODUCING NEUTRON IMAGES

Edward Emanuel Sheldon, New York, N. Y.

Original application March 9, 1948, Serial No. 13,916. Divided and this application April 21, 1948, Serial No. 22,393

17 Claims. (Cl. 313—65)

1

This application represents a division of my co-pending application Ser. No. 13,916 filed March 9, 1948, now U. S. Patent No. 2,555,424, issued June 5, 1951, and relates to a new method and device of producing neutron images.

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

Another object of this invention is to make it possible to prolong the fluoroscopic examination of patients since it will markedly reduce the strength of radiation affecting the patient's body.

Another object of this invention is to reduce the time necessary for neutron photography.

Another object of this invention is to reduce the energy necessary for neutron photography.

Another object is to provide a method and device to produce sharper and of a greater contrast neutron images than it was possible up to now.

The purposes of this invention were accomplished by the use in combination of a neutron source, such as e. g. radium with beryllium or nuclear particles accelerator like cyclotron, of a novel intensifying system comprising fluorescent screen, an optical system, television pickup tube and means of inspection and recording said neutron image obtained in intensified form in the final receiver. In this intensifying system the neutron image of the examined body is produced in fluorescent form by the fluorescent screen, is projected by the optical system onto the photocathode of the television pickup tube, is converted in the pickup tube into video signals and is sent in form of video signals to immediate or remote receivers for visual observation or for photographic or facsimile recording. Better results are obtained by the use of reflective optical system. The reflective optical system gives five-eight gain in light reaching the photocathode of the television pickup tube from the fluorescent screen as compared with the use of other optical systems. This improvement is of special importance in medical fluoroscopy and radiography of patients where the luminosity of the neutron image is limited by the amount of the neutron energy which the patient's tissues can tolerate without damage. The reflective optical system

2

used in my invention consists of concave spherical mirror and an aspherical correction plate. In some instances it is advantageous to use an auxiliary convex or plane mirror disposed between the reflecting surface of the concave mirror and its nearest conjugate focus. In such case the concave spherical mirror is provided with window in its center in order to allow positioning of the pickup tube on the opposite side of the reflecting surface.

There was also obtained a marked increase in the light reaching the photocathode of television pickup tube by the use of a novel fluorescent screen. This improvement is also of a special importance in the medical neutron fluoroscopy and photography of patients as, it was explained above, the luminosity of neutron image is limited by the amount of neutron energy which the patient's tissues can tolerate without damage. The novel neutron screen has fluorescent layer enriched with elements responsive to neutron radiation such as gadolinium, boron, cadmium, or paraffine or their isotopes. In some instances it is more advantageous to use a composite fluorescent screen consisting of neutron reactive layer, of thin barrier layer transparent to radiation emitted by said neutron reactive layer, of light reflecting layer and of fluorescent layer.

In another alternative of this invention especially suitable for examination of patients with neutrons, where the energy of neutron source must be limited to avoid damage to the tissues, a neutron reactive or neutron fluorescent layer is coated with an extremely thin photo-emissive layer and is positioned within a specially designed television pickup tube. This combination when properly executed results in a considerable improvement in efficiency because of the marked gain in light reaching the photo-emissive layer. The importance of this construction is clear when it is considered that the most sensitive television pickup tube has a threshold of operation of approximately .01 millilamberts at which level the sharpness of produced image is unsatisfactory. It is obvious therefore that the elimination of an optical system disposed between fluorescent screen and standard television pickup tube presents an important improvement in securing the necessary amount of light for satisfactory operation of the tube as well as a marked improvement in the sharpness of the image. Elimination of the lens alone and using the fluorescent screen outside of the pickup tube would result in separation of the fluorescent layer from the photosensitive layer and

would cause a marked diffusion and deterioration of the sharpness of the image making impossible correct diagnosis. The close opposition of the fluorescent or neutron reactive layer and photo-emissive layers according to this invention made possible by the positioning of the fluorescent screen inside of the tube overcomes diffusion of the image and therefore represents an important improvement. Further improvement in the operation of this neutron sensitive pickup tube can be obtained by the use of a thin reflecting layer of aluminum or similar material sprayed on the surface of the fluorescent layer nearest the source of radiation to increase the transfer of light from fluorescent to the photo-emissive layer.

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

In the drawings:

Fig. 1 is a cross sectional view of neutron image producing system showing the position of fluorescent screen, optical system and neutron pick-up tube in accordance with this invention.

Fig. 2 is a cross sectional view of an alternative form of the optical system.

Fig. 3 is a sectional view of neutron sensitive fluorescent screen.

Fig. 4 is a sectional view of neutron sensitive pick-up tube.

Fig. 5 is a sectional view of front portion of the neutron sensitive pick-up tube in which thin barrier layer interposed between the fluorescent and photoemissive layers is illustrated.

Fig. 6 is a sectional view of the front portion of the neutron sensitive pick-up tube in which light reflecting layer is illustrated.

Fig. 7 is a sectional view of the front portion of the neutron sensitive pick-up tube in which neutron reactive layer is illustrated, separately from fluorescent layer.

Fig. 8 is a sectional view of the front portion of the neutron sensitive pick-up tube in which neutron reactive layer and secondary electron emissive layer are illustrated.

Fig. 9 is a sectional view of an alternate form of neutron sensitive pick-up tube having additional intensifying section.

Fig. 10 is a sectional view of the neutron image intensifying system showing in addition neutron image storage tube.

Fig. 11 is a sectional view of the neutron image intensifying system showing in addition an alternate form of image storage tube.

Reference will now be made to Fig. 1 which shows neutron source 1, the examined body 2, the fluorescent screen 3 of ZnS and its derivatives or of other phosphors and enriched with elements sensitive to neutrons such as e. g. boron, cadmium, uranium or plutonium and their isotopes, a neutron image 4, the reflective optical system 5 which in this particular case consists of aspherical correction plate 5*a* and of spherical concave mirror 5*b*, but which may have different forms also, the television pickup tube 6 and the final receiver of kinescope type 14 or a facsimile type 16, which is shown in Fig. 2.

The neutrons after the passage through the examined body form an invisible neutron image 4 which is converted in the fluorescent screen 3 into a visible fluorescent image 4*a*. The fluorescent screen in some instances consists of neutron reactive layer 3*a* such as boron, cadmium, gadolinium, plutonium, or paraffine, of very thin barrier layer 3*b* transparent to radiation emitted by said neutron reactive layer, of very thin light reflecting layer 3*c* and transparent to radiation emitted by said neutron reactive layer, and of fluorescent layer of ZnS 3*d* and its derivatives as illustrated in the Fig. 3.

The fluorescent image is projected by the reflective optical system 5 on the photocathode 7 of the television pickup tube 6. Fluorescent neutron image creates in the photocathode 7 electron image which is focused by means of magnetic or electrostatic fields on the target 8 where it is intensified by secondary electron emission and is stored. The target 8 is scanned by electron beam 9. The latter is modulated by the electron pattern on the target so that the returning electron beam 10 brings the charges corresponding to the pattern of the electron image of the target to the multiplier section 11 where they are intensified by secondary emission and sent in the form of video signals to the amplifier system 15 and therefrom to immediate or remote receivers 14 by coaxial cables 13 or by high frequency system 12. In the receiver the original neutron image can be reproduced with desired intensification allowing examination of fluorescent neutron images in the daylight and the use of photopic vision characterized by full visual acuity for the contrast and detail which was the primary object of this invention. The television pickup tube used in this invention can be of intensity modulation type, of deflection modulation type, of velocity modulation type, or of photoconductive type and it is obvious that various types of television pickup tubes can be used without affecting the idea of this invention. The focusing and synchronizing circuits 18 are not shown in detail as they are well known in the art and would only complicate the drawings. The photocathode can be flat or curved depending on the shape of fluorescent screen or on the type of the optical system to be used. In the alternative form of this invention shown in Fig. 2, the concave spherical mirror 5*c* has an aperture in its center 17. An auxiliary convex spherical mirror 5*d* or a plane mirror is disposed between the reflecting surface of the concave mirror and its nearest conjugate focus. The pickup tube 6 is disposed in this case opposite the reflecting surface of the concave spherical mirror in the axis of its aperture. The photocathode should be preferably of spectral sensitivity correlated with the fluorescence of the screen. A suitable combination is a fluorescent screen of ZnSAg and photocathode of cesium, potassium or lithium on antimony, bismuth or arsenic. An important improvement in functioning of the whole system can be obtained by having the target of the television pickup tube of conductivity and resistivity allowing for longer storage time of electron image. The contrast of the original neutron image can be markedly increased by the use of amplifier system 15 in the receiver having variable mu tubes with circuit so designed that the grid bias of the variable mu tube is smaller at high signal levels than at low signal levels which represents another important object of this invention as neutron diagnosis is mainly based on differences in luminosity or photographic density in the adjacent areas of neutron image.

Furthermore the time of exposure or neutron energy can be markedly reduced, which was another purpose of this invention. Furthermore the grain of photographic emulsion can be reduced without necessity of prolongation of the

time of exposure which will result in pictures of better detail.

Fig. 4 shows another alternative of this invention in which the purposes of the invention were accomplished by the use of a novel composite neutron sensitive screen placed in specially designed television pickup tube. The composite neutron screen 31 consists of neutron fluorescent layer 32 of ZnS or its derivatives and enriched with boron, gadolinium, cadmium, or uranium and their isotopes and of photo-emissive layer 33 such as e. g. cesium, potassium or lithium on antimony or bismuth. The invisible neutron image is converted into visible light image in the neutron fluorescent layer and activates the photo-emissive layer producing photo electron image corresponding to pattern of neutron image. The photoelectron image is increased by secondary emission and is stored in the target 19 of the novel television pickup tube 25 and is scanned by electron beam 26. The latter is modulated by the electron pattern on the target so that the returning electron beam brings the charges corresponding to the pattern of the electron image to the multiplier section 27 where they are intensified by secondary emission and sent in the form of video signals to the amplifier system and therefrom to immediate or remote receivers 28 by coaxial cable 29 or by high frequency system 30. In the receiver the original neutron image can be reproduced with desired intensification and amplification of the contrast.

Further improvement in the operation of this neutron sensitive pickup tube can be obtained by the use of a thin barrier layer 20 interposed between neutron fluorescent layer 32 and photoemissive layer 33 in form of a sheet as illustrated in Fig. 5. The light transparent layer can be a very thin film of mica, glass, silicates, fluorides or of a suitable plastic like vinyl derivatives. The light transparent layer can be also made in form of a fine mesh or screen. In some instances it is advantageous to place a thin light reflecting layer 21 on the side of fluorescent layer 32 closer to the source of radiation. The light reflecting layer 21 must be transparent to neutron radiation, as illustrated in Fig. 6.

Further improvement may be accomplished by the use of a separate neutron reactive layer 22 such as e. g. of cadmium, boron, gadolinium, plutonium or paraffine and their isotopes in a position to the fluorescent layer 32, as illustrated in Fig. 7.

In some instances it is more advantageous to use composite neutron sensitive screen consisting of neutron reactive layer 23 such as for example of gadolinium and of secondary electron emissive layer 24 as illustrated in Fig. 8. Considerable improvement in operation of neutron sensitive pick-up tube was obtained by the use of special image intensifying section 34 in the neutron sensitive pick-up tube 35, see Fig. 9. The neutron image 36 is converted in the fluorescent layer 37 of the composite photocathode 38 into fluorescent image and then in the photoemissive layer 39 into photoelectron image. The light reflecting layer 45 of the photo-cathode serves to obtain better utilization of the fluorescent light. Light transparent layer 46 separates the fluorescent and photoemissive layers. The photoelectron image having the pattern of the neutron image is focused by means of magnetic or electrostatic fields on the first composite screen 40 of the image intensifying section 34 of the tube. The intensifying section 34 has one or a few successively arranged composite screens 40 each of them consisting of electron pervious, light reflecting layer 41, of layer 42 fluorescing when irradiated by electrons, of chemically inactive barrier layer 43 transparent to fluorescent light and of photoemissive layer 44. Fluorescent substances which may be used for the composite screen are zinc silicates, zinc selenides, zinc sulphides, calcium tungstate or $BaPbSo_4$, with or without additional activators. The satisfactory photoemissive materials are caesium oxide activated by silver, caesium with antimony or with bismuth or antimony with lithium or potassium. The barrier layer 43 between the fluorescent and photoemissive surfaces can be very thin light transparent layer of mica, glass, ZnF_2, of silicates or of a suitable plastic. The electron pervious light reflecting layer 41 may be of aluminum or of silver. The photoelectron image from the photocathode 38 focused on the composite screen 40 causes fluorescence of its fluorescent layer 42 which activates the photoemissive layer 44 producing an intensified photoelectron image having the pattern of the neutron image. The intensified photoelectron image can be again focused on next composite screen 47, whereby its further intensification is achieved.

The fluorescent layer in the composite photocathode and in the composite screens should be pitted with multiple cone-like or pyramid-like depressions. In this way the emission of fluorescence is increased in the ratio equal to the relation between the surface of the cone and the surface of the base of the cone and is therefore many times larger than the fluorescence of an even fluorescent screen.

In some instances, it is advantageous to demagnify the photoelectron image emitted by the composite photocathode 38 before projecting it on the composite screen 40 of the intensifying section 34. The electron diminution of the image is accomplished by means of electrostatic or magnetic fields which are well known in the art and therefore are omitted in order not to complicate drawings.

In some applications it may be preferable to use in conjunction with intensifying section 34 the electron multiplier section 48 consisting of one or few stages of secondary electron multipliers 49 which serves to intensify further the electron image. In such a case the photoelectron image from the composite photocathode is focused by means of electrostatic or magnetic fields on the first stage 49 of the multiplier section. This results in intensification of the electron image by secondary emission. The secondary electrons emitted from the first stage and having the pattern of the neutron image may be focused after acceleration on the second stage of the multiplier section, producing thereby further intensification of the electron image. The electron image produced by electron multiplier section of the tube is projected on the first composite screen 40 of the intensifying section 34 of the neutron pick-up tube for further intensification. The electron image produced by the intensifying section of the tube is focused on the two-sided target 50 producing therein pattern of electrical charges corresponding to the neutron image. The electron image can be stored in the target for a predetermined time by choosing proper resistivity and conductivity of target material. The target 50 is scanned by electron beam 51 from the electron gun 52. The scanning electron beam is modulated by the pattern of electrical charges of the

target so that the returning beam 53 carries video information. The returning electron beam strikes the first stage of the electron multiplier 54. The secondary electrons from the first stage of the multiplier strike the succeeding stage 55 around and in the back of the first stage. This process is repeated in a few stages resulting in a marked multiplication of the original electron signals. The signal currents from the last stage of the multiplier are fed into television amplifiers 56 and then sent by coaxial cable 57 or by high frequency waves to the receivers of kinescope type 58 or facsimile type 59 in which they are reconverted into visible image 60 for inspection or for recording. In order to obtain intensification of contrast of the neutron image the amplifiers 56 are provided with variable mu tubes in one or two stages. Small differences in intensity of the succeeding video signals are increased by variable mu tubes in nonlinear manner resulting in a gain of the contrast of the visible image in receiver. The focusing, synchronizing and deflecting circuits 61 are not shown in detail as they are well known in the art and would complicate drawings. An improvement in operation of the neutron pick-up tube was obtained by the use of a special storage tube, see Fig. 10. By the use of storage tube 62 the scanning time in the neutron pick-up tube can be prolonged, as well as the frame time, resulting in a proportionally greater electron output of the composite photocathode. The flicker caused by prolongation of frame time can be in this way successfully eliminated. The neutron image after conversion into video signals, as described above, is sent from the neutron pick-up tube 35 to the storage tube 62 and is deposited there by means of modulating electron scanning beam 63 of said storage tube, in a special target 64 in which it can be stored for a predetermined time. The stored electrical charges having the pattern of neutron image are released from the target 64 by scanning it with another electron beam 65. The electron image released from storage is converted again into video signals and sent to final receivers 69 to produce visible image. In another variety of the storage tube, see Fig. 11, the neutron image is stored in the photocathode 66 of the storage tube 67 by modulating the electron scanning beam 63 of said storage tube and is released by irradiating said photocathode with ultraviolet or blue light. An additional electron beam 68*a* serves to wipe off the remaining electron charges in the photocathode before storing another neutron image. The electron image released from storage by the action of light is converted again into video signals and sent to final receivers 69 to produce visible image. The focusing, synchronizing and deflecting circuits are not shown as they are well known in the art and would serve only to complicate drawings.

Although particular embodiments and forms of this invention have been illustrated it is understood that modifications may be made by those skilled in the art without departure from the true scope and spirit of the foregoing disclosure.

What is claimed is:

1. A vacuum tube sensitive to an atomic particles image comprising means for receiving an atomic particles image and converting said image into the second atomic particles image, a two-sided target, means for projecting said second atomic particles image onto said target, and means for scanning said target with an electron beam from the side opposite to the impingement of said second atomic particles image on said target to convert said second image on the target into video signals.

2. A device as defined in claim 1, wherein said atomic particles image receiving means comprise luminescent means activated with elements sensitive to said atomic particles.

3. A vacuum tube as defined in claim 1, wherein said means for receiving atomic particles image comprise means activated with elements sensitive to said atomic particles for converting said image into an electromagnetic radiation image, and of means for converting said electro-magnetic radiation image into the second atomic particles image.

4. A device as defined in claim 1, wherein said image receiving means comprise an atomic particles reactive layer and a luminescent layer.

5. A device as defined in claim 1, wherein said image receiving means consist of a screen reactive to said atomic particles and converting said atomic particles into a beam of the second atomic particles.

6. A device as defined in claim 1, wherein said atomic particles image receiving means comprise means for converting said image into the second atomic particles image and means for converting said second atomic particles image into the third atomic particles image.

7. A device as defined in claim 1, wherein said vacuum tube has means for collecting electrons of said electron beam returning after scanning said target and means for converting said collected electrons into video signals.

8. A device as defined in claim 1, wherein said image receiving means consist of a luminescent layer activated with elements reactive to atomic particles, a light transparent separating layer, and a photoemissive layer.

9. A vacuum tube enclosing means for receiving an atomic particles image comprising a luminescent layer activated with elements sensitive to said atomic particles, a light transparent separating layer independent of walls of said tube and transparent also to ultra-violet radiation and a photoelectric layer, said tube further enclosing image from said photoelectric layer into video means for converting image from said photoelectric layer into video signals.

10. A device as defined in claim 9, wherein said atomic particles image receiving means comprise an atomic particles reactive layer, a luminescent layer, a light transparent separating layer independent of walls of said tube and transparent also to ultra-violet radiation and a photoelectric layer.

11. A device as defined in claim 9, wherein said luminescent layer has a light reflecting layer on the side facing said atomic particles image.

12. A device as defined in claim 9, wherein said separating layer is of conducting type.

13. A device as defined in claim 10, wherein said separating layer is of a conducting material.

14. A vacuum tube enclosing means for receiving an atomic particles image, said means comprising a luminescent layer activated with elements reactive to said atomic particles, a light transparent separating layer independent of wall of said tube and a photoemissive layer for converting said image into a photoelectron image, said tube further enclosing means for converting said photoelectron image into video signals.

15. A device as defined in claim 14, wherein said atomic particles image receiving means comprise an atomic particles reactive layer, a lumi-

nescent layer, a light transparent separating layer independent of wall of said tube, and a photoemissive layer.

16. A vacuum tube enclosing means for receiving an atomic particles image, said means consisting of a luminescent layer activated with elements reactive to atomic particles, a light transparent conducting separating layer, and a photoemissive layer for converting said particles image into a photoelectron image, said tube further enclosing means for converting said photoelectron image into video signals.

17. A vacuum tube enclosing means for receiving an atomic particles image, said means consisting of an atomic particles reactive layer, a luminescent layer, a light transparent conducting separating layer, and a photoemissive layer for converting said particles image into a photoelectron image, said tube further enclosing means for converting said photoelectron image into video signals.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,838,537	Dauvillier	Dec. 29, 1931
1,942,501	Stilwell	Jan. 9, 1934
2,158,853	Coolidge	Aug. 16, 1939
2,198,479	Langmuir	Apr. 23, 1940
2,219,113	Ploke	Oct. 22, 1940
2,234,806	Ploke	Mar. 11, 1941
2,270,373	Kallman	Jan. 20, 1942
2,297,478	Kallman	Sept. 29, 1942
2,305,452	Kallman	Dec. 15, 1942
2,319,712	Williams	May 18, 1943
2,344,042	Kallman	Mar. 14, 1944
2,344,043	Kallman	Mar. 14, 1944
2,354,199	Collins	July 25, 1944
2,477,307	Mockto	July 26, 1949
2,555,424	Sheldon	June 5, 1951

FOREIGN PATENTS

Number	Country	Date
315,362	Great Britain	Feb. 2, 1929