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2,945,973

IMAGE DEVICE

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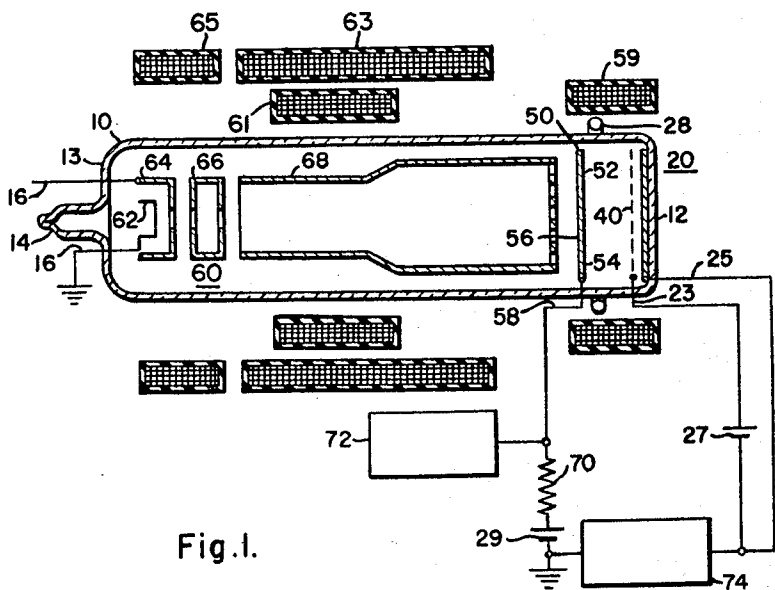


Fig. 1.

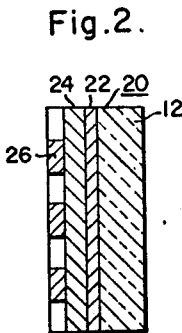


Fig. 2.

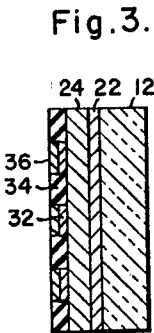


Fig. 3.

WITNESSES

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2,945,973

IMAGE DEVICE

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This invention relates to electron discharge devices and more particularly to those tubes in which a radiation image is received on an input screen and produces output signals which may be used to reconstruct the radiation image. This invention is particularly useful in pickup tubes such as those described in copending application Serial No. 416,879, entitled X-Ray Image Intensifying Device, filed March 17, 1954, and an application entitled An Image Device, Serial No. 584,231, filed May 11, 1956, and issued March 15, 1960, as Patent 2,928,969, both by R. J. Schneeberger and assigned to the same assignee as the present invention.

In an image intensifying device of this type a radiation image such as X-rays is focussed upon an input screen which emits electrons at a rate proportional to the brightness of each element. The radiation may be focussed directly on a photoemissive material or may be converted by means of a phosphor into another wave length of radiation to which the photoemissive material is sensitive. The electrons within the photoelectron image generated by the input screen are accelerated to a velocity of the order of 10 to 20 kilovolts and focussed to a reduced size upon a target electrode. The target member is comprised of a semi-insulating layer of a material exhibiting the property of electron bombardment induced conductivity with an electrical conductive backing plate on the side of the semi-insulating layer facing the input screen and on which the photoelectron image is focussed. The photoelectrons from the input screen penetrate through the thin electron permeable electrical conductive backing layer of the target and penetrate into the semi-insulating layer. The semi-insulating layer has a resistivity in the order of 10^{12} ohms per cubic centimeter. The penetration of the electrons into the semi-insulating layer produces what may be thought of as a conductive image duplicating the spaced distribution of the electron image from the input screen and so of the radiation image directed onto the input screen.

It is necessary that a polarizing voltage be applied across the semi-insulating layer. The backing plate serves as one of the electrodes for applying the field across the semi-insulating layer and instead of a second electrode on the other surface of the semi-insulating layer an electron gun is utilized to deposit a charge on the exposed surface of the semi-insulating layer. The electron gun scans the exposed or free surface of the semi-insulating layer to bring the entire surface to a potential similar to that applied to the cathode of the electron beam generating gun. In the absence of a radiation image directed onto the input screen, the surface

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of the semi-insulating layer of the target facing the electron gun is maintained at the cathode potential by the electron scanning beam. A positive potential is applied to the backing plate of the target of the order of 50 volts positive with respect to the cathode potential of the scanning beam gun and therefore a field of 50 volts exists between the free surface of the semi-insulating layer and the backing plate layer.

When a radiation image is projected onto the input screen, photoelectrons from the input screen bombard the target and induce conductivity in the semi-insulating layer in a transverse direction. Since the semi-insulating layer is extremely thin, very little lateral conductivity will exist and therefore excellent resolution is obtained. The semi-insulating layer acts in a manner similar to a leaky capacitor resulting in the scanned or free surface of the semi-insulating layer changing from the cathode potential of the scanning gun to some positive potential not greater than the target voltage. This effect on the semi-insulating layer may be referred to as a conductivity image. The change in potential or charge on the surface elements of the scanned surface of the semi-insulator is proportional to the intensity of the electron bombardment by the photoelectrons from the input screen. When the low velocity scanning electron beam moves across the surface of the target each target element will be restored to the cathode potential of the scanning beam gun. A signal may be derived from the backing plate corresponding to the restoring charge derived from the scanning beam. The output signal may be employed in a conventional manner for transmission or direct connection to a conventional display device.

The device described in the above-mentioned applications obtains a very good signal to noise ratio at low levels of radiation energy. A target such as described above using a semi-insulating material of arsenic trisulfide has been found to exhibit amplifications as high as one thousand with an accelerating voltage of 20 kilovolts and a field of 50 volts. It is advantageous to obtain a signal to noise ratio as high as possible with a given scene brightness. For example, a signal to noise ratio of 50 is a relatively snow-free picture. It is found that a target current of 10^{-7} amperes is needed to produce a signal which is 50 times the noise power inherent of the first stage of the conventional video amplifier connected to the output of the target. For example, with a target amplification of one thousand, a photoemissive current of 10^{-10} amperes is required to produce an output current of 10^{-7} from the target. A typical photoemissive cathode will emit electrons at the rate of 10^{-11} amperes at the lowest fluoroscopic levels used in X-rays and which provide a relatively snow-free picture.

It is therefore desirable to provide some method of improving the response of the image section of the pickup tube to permit operation at light levels where sensitivity is limited only by the noise of the photoelectric emission from the photocathode of the device.

The image orthicon type of pickup tube does not have as much amplification as the image device described in copending application Serial No. 525,594, filed August 1, 1955, and issued August 18, 1959, as Patent 2,900,555, entitled Bombardment Conducting Target by R. J. Schneeberger and assigned to the same assignee as the present invention. The image orthicon utilizes amplifica-

tion of the return portion of the scanning beam in a well-known manner. The disadvantage of this type of amplification is that the maximum return beam current and therefore the maximum noise occurs with minimum video or low light level signals. It is therefore desirable to place some type of internal amplification within the pickup tube and prior to the scanning beam and therefore derive, if possible, the amplified signal directly from the target. This type of amplification contributes only a negligible amount of noise to the amplified signal obtained from the target electrode. In particular this invention is directed to a pickup tube in which the image section is modified in order to obtain a maximum amount of photoelectrons bombarding the target member with a given light level.

It is therefore an object of my invention to provide an improved type of pickup tube.

It is another object to provide an improved pickup tube having high signal to noise ratio.

It is another object to provide a pickup tube having acceptable reproduction of a scene at extremely low brightness levels.

It is another object to provide a pickup tube which permits self-dividing a scene of fixed brightness into smaller elements while maintaining the original signal to noise ratio.

It is another object to provide an improved pickup tube having a target electrode depending on electron bombardment induced conductivity type material.

These and other objects are effected by my invention as will be apparent from the following description taken in accordance with the accompanying drawing throughout which like reference characters indicate like parts and in which:

Figure 1 is a schematic view partly in section of a tube embodying the principles of my invention;

Fig. 2 is a sectional view on an enlarged scale of the input screen in Fig. 1; and

Fig. 3 is a sectional view of a modified input screen.

Referring in detail to Figs. 1 and 2, a vacuum-tight enclosure or envelope 10, which may be of any suitable material such as glass and of any suitable configuration, is provided. In the specific embodiment shown, the envelope 10 is essentially a tubular member closed at one end with an input window 12 and the other end closed with a button-like stem 13. The button stem 13, normally of glass, consists of a centrally located tubular member 14 for evacuating and sealing off the envelope 10 and also a plurality of lead-in members 16 for applying voltages to the electrode members within the envelope. An input screen 20 is normally positioned on the input window 12 of the tube or may be in some cases separated therefrom and provided with a transparent glass support member. In the specific embodiment shown, the input window 12 serves as the support member for the input screen 20 and is provided with a transparent conductive coating 22 on the inner surface of the window 12 of a material such as stannic oxide. An inlead 25 connected to the transparent electrical conductive coating 22 is provided to the exterior portion of the envelope 10. The window 12 and coating 22 are transparent to the wave lengths of the radiations to be detected. A light-sensitive layer 24 of a photoconductive material is positioned on the exposed surface of the transparent conductive layer 22. The layer 24 is of a material that exhibits the property of a decrease in resistivity when exposed to radiations to be detected, such as X-rays, visible light and infrared. It is necessary to select the specific photoconductive material in order that it be responsive to the wave length of the radiation. Suitable photoconductive materials are selenium, antimony trisulfide, cadmium sulfide, lead telluride or any other known photoconductive material.

Deposited on the surface of the photoconductive layer 24 is an electron-emissive layer 26. The electron-emis-

sive layer 26 is of a material that emits electrons in response to radiation such as gold, cesium antimonide, cesium-silver-oxygen or any one of the many other well-known photoemissive materials. The layer 26 may be continuous or mosaic. In the structure shown in Figs. 1 and 2, a mosaic layer 26 is shown. The layer 26 is illuminated by a light source 28. The wave length of the light source 28 is such as to be in the region which the material in the layer 26 is sensitive. In this embodiment, it would also be necessary that the photoconductive layer 24 be insensitive to radiations from the auxiliary light source 28 and the electron-emissive layer 26 must be insensitive to the input radiations.

An alternative input screen is shown in Fig. 3. The screen consists of an interleaved structure of opaque conductive elements 32 and insulating elements 34 evaporated over the photoconductive layer 24. The photoemissive elements 36 would then be deposited over the conductive areas. The conductive elements 32 can be any of a number of metals compatible with the particular photoconductive materials and photoemissive materials utilized. The insulating material in the elements 34 must also be compatible with the other materials and be opaque to any radiation from auxiliary source 28 to which the photoconductive layer 24 is sensitive. It is also obvious that the insulating material used should not be photoconductive to the auxiliary radiation. In the structure shown in Fig. 3, gold could be used for both the conductive elements 32 and the emissive elements 36 and antimony trisulfide as the insulator elements 34 in the case where the radiation from the auxiliary source 28 was of the wave length of about 2,537 angstrom units in the ultraviolet region. Both the gold and antimony trisulfide should be several microns thick in order to prevent transmission of the ultraviolet light from the auxiliary light source 28 onto the photoconductive layer 24.

A grid member 40 is positioned adjacent to the input screen 20 and is of a suitable conductive material such as nickel having large open areas. An inlead 23 is also provided from the grid electrode 40 to the exterior portion of the envelope.

A target member 50 is positioned on the opposite side of the grid member 40 with respect to the input screen 20 and is comprised essentially of the metallic support mesh structure 52 of a material such as copper or nickel having a large open area. On the opposite side of the support mesh 52 with respect to the input screen is a continuous backing layer 54 of a suitable electrical conductive material such as aluminum. The backing layer 54 is sufficiently thin so as to be essentially permeable to electrons accelerated from the input screen 20. On the opposite surface of the backing layer 54 with respect to the mesh support structure 52 is deposited a thin layer 56 of a semi-insulating material of a resistivity greater than 10^{12} ohms per cubic centimeter in the unexcited state such as arsenic trisulfide, antimony trisulfide, or amorphous selenium which exhibit the property of electron bombardment induced conductivity. The backing layer 54 is also provided with an inlead 58 to the exterior portion of the envelope 10.

The portion of the tube and electrodes on the input screen side of the target 50 is normally referred to as the image section of the pickup tube. It is necessary to provide electrostatic or magnetic means for focussing the electrons emitted from the input screen 20 and also to provide acceleration to the target member. In the specific embodiment shown, a focussing coil 59 is illustrated for providing the necessary focussing of the electrons emitted from the input screen 20 and directed onto the target member 50. The acceleration is provided by means of a suitable voltage source 74 connected between the inleads 23 and 58. The section of the tube on the opposite side of the target member 50 with respect to the input screen 20 is normally referred to as the scanning

section of the pickup tube. An electron gun 60 for generating an electron beam of low velocity is provided within the scanning section of the tube, and the electron beam is directed onto the exposed surface of the semi-insulating layer 56 of the target member 50. The electron gun may be of any suitable type and is normally comprised of a cathode 62, a control grid 64, an accelerating electrode 66 and an anode 68 which generates a low velocity beam. This beam may be caused to scan a raster on the exposed surface of the insulating layer 56 of the target 50 by means of deflection coils, focussing coils and alignment coils of suitable forms well known in the art which are illustrated by coils 61, 63 and 65. Inleads from the cathode 62, control grid 64, accelerating electrode 66, and anode 68 pass through the button stem 13 of the tube, and suitable potentials are applied thereto. In the specific embodiment shown in Fig. 1, the cathode 62 is shown connected to ground for the purposes of explaining the operation of the device.

The inlead 25 is connected to the source 74 so that the input screen 20 normally operates at a potential of the order of 20,000 kilovolts negative with respect to ground, and the control grid 40 operates at a potential of the order of 50 to 100 volts positive with respect to the input screen 20 by means of a battery 27. The inlead 58 to the target electrode 50 is connected through an output resistor 70 to a voltage source 29 to provide an operating voltage of about 50 volts positive with respect to ground, and the voltage developed across the output resistor 70 is connected to a suitable video amplifier 72.

The mode of operation of the device may be described somewhat in the following manner. If it is assumed that the radiation image is not projected onto the tube, the scanning electron gun 60, which is operating below first crossover of the semi-insulating material layer 56, will charge the surface to the potential of the cathode 62 of the gun 60 which is ground potential. The backing layer 54 will be 50 volts positive with respect to ground and the scanned surface of the semi-insulating layer 56. The potential difference between the input screen and the target is of the order of 10 to 20 kilovolts. It is necessary to operate at such potentials in order to induce conductivity within the target member 50. The conductivity induced in a given material under electron bombardment is a function of both the thickness of the material and the intensity; that is, energy or numbers of the bombarding electrons. The maximum gain is obtained when the bombarding electrons have just enough energy to penetrate through the backing layer 54.

Practical considerations such as variation in velocity of the reading electrons from the electron scanning beam gun place a lower limit on the minimum voltage difference which can be read out. As a result, the detectable charge difference becomes smaller as the capacitance per element decreases or as the film thickness increases. In practice, a semi-insulating film thickness of the order of 1 to 2 microns and bombarding energy of 10 to 20 kilovolts appears to be of optimum value. The voltage across the photoconductive layer 24 must be limited to 50 to 100 volts or the layer will be destroyed. It is therefore necessary to insert the grid member 40 between the input screen 20 and the target 50 in order to prevent voltage breakdown in the photoconductive layer 24 in the input screen 20. In operation, this grid is made 50 to 100 volts positive with respect to the conductive layer 22 in the input screen.

If it is now assumed that the auxiliary light source 28 continuously illuminates the electron-emissive layer 26 of the input screen 20 with no input radiation image directed on the photoconductive layer 24, the photoconductive layer 24 is of high resistivity, and the surface of the electron-emissive layer 26 will tend to charge positively toward the potential of the grid 40. This potential may be referred to as the equilibrium potential. It is im-

portant that the grid 40 be spaced very closely to the electron-emissive layer 26, and normally its spacing should be equivalent to the spacing between the adjacent wires of the mesh member 40. In this state, very few electrons will be accelerated to the target 50.

If it now is assumed that the radiation image is directed onto the input screen 20, the radiation image will cause the photoconductive layer 24 to be more conductive corresponding to the radiation incident on each elemental area of layer 24. The corresponding elemental areas on the surface of the electron-emissive layer 26 will tend to go negative with respect to the equilibrium potential which will allow the electrons emitted from the electron-emissive layer 26, due to radiations from source 28, to pass through the grid member 40 and be accelerated to the target electrode 50. The number of electrons emitted by the electron-emissive layer 26 will substantially be equal to the charge passed through the photoconductive layer 24 which would correspond to the change in conductivity of the photoconductive layer 24 in response to the intensity of the radiation.

The electrons thus emitted from the input screen 20 would form an electron image which duplicates the space distribution and the intensity of the radiation image projected onto the input screen 20. The electron image thus generated from the input screen 20 is accelerated and focussed by means of the potential applied between the input screen 20 and the target member 50 and also by the magnetic field provided by the coil 59. The electron image from the input screen 20 produces a conductive image in the semi-insulating layer 56, and the respective areas of the exposed surface of the semi-insulating layer rise from ground potential to a fraction of the potential applied to the conductive backing layer 54 of the target. This potential pattern on the surface corresponds to the variation of the conductivity image over its surface. When the electron beam generated by the electron gun 60 strikes a particular element or area on the surface of the semi-insulating layer 56, it deposits sufficient electrons to recharge the potential on the surface of the semi-insulator to the potential of cathode 62 of the scanning beam gun 60. A low velocity beam is utilized in this structure. As a result of this recharging action of the scanning beam, a corresponding charge current flows through the output resistor 70 connected to the target 50 and may be used in a well-known manner. The output signal may be used to modulate a television transmitter or may be connected directly to an image reproducing device and thereby brighten, enlarge or vary contrast by standard television techniques.

Another type of operation would be to pulse the auxiliary radiation source 28. In this operation without a radiation image directed onto the tube, the first pulse of light from the auxiliary light source 28 would cause the electron-emissive layer 26 to charge to a potential substantially equal to the potential on the grid 40 in what may be again referred to as an equilibrium potential. With the auxiliary light source 28 turned off and the radiation image directed onto the input screen 20, the electron-emissive layer 26 would be charged negatively with respect to the equilibrium potential so that a charge pattern would be built upon the surface of the electron-emissive layer 26 corresponding to the radiation image directed on the photoconductor layer 24. In this operation, the resistivity of the photoconductive layer 24 is decreased, and the charge is allowed to flow through the photoconductive layer 24 to the electron-emissive layer 26. When the auxiliary light source 28 is again pulsed, the electrons from the input screen 20 from elemental areas having a more negative potential than the equilibrium potential will be accelerated through the grid 40 to strike the target 50 with high energy and induce conductivity in the semi-insulating layer 56. The number of electrons allowed to pass through the grid 40 will substantially correspond to the amount of voltage difference

between the elemental areas and the equilibrium potential of the electron-emissive layer 26.

By utilizing the photoconductive layer 24 in combination with the electron-emissive layer 26, one is able to obtain electron multiplying properties of thin insulating films combined with the high quantum yield of photoconductors in order to obtain a high sensitive radiation image pickup tube. Photoconductive materials have quantum yields much greater than one, while photoemissive materials have yields of only about 0.1.

While I have shown my invention in several forms, it will be obvious to those skilled in the art that it is not so limited but is susceptible to various other changes and modifications without departing from the spirit and scope thereof.

I claim as my invention:

1. An electron discharge device comprising a target member including a film of material exhibiting the property of electron bombardment induced conductivity above a predetermined value of electron energy, means for generating an electron beam having energies below said predetermined value to bombard one surface of said film to establish an equilibrium potential on the surface of said film, an electrical conductive sheet in contact with the opposite surface of said film to maintain the opposite surface at a fixed potential different from said equilibrium potential, an input screen spaced from said target for projecting electrons having energies above said predetermined value onto said target member to set up a conductivity image within said film corresponding to the electron image generated by said input screen, said input screen comprising a layer of photoconductive material sensitive to the radiation of the image to be detected sandwiched between a photoemissive layer insensitive to said input radiation and a conductive layer, said photoemissive layer facing said target, a grid member positioned between said photoemissive layer and said target member and adjacent to the surface of said photoemissive layer, means for applying a potential between said conductive layer and said grid and means for illuminating said photoemissive layer with radiation to which said photoemissive layer is sensitive and to which said photoconductive layer is insensitive.

2. An image pickup tube comprising a vacuum-tight envelope having a photosensitive input screen adjacent one end of said envelope, a target member positioned from said input screen within said envelope, said target comprising a thin conductive layer and a layer of semi-insulating material supported on the surface of said conductive layer opposite from said input screen, said layer of semi-insulating material exhibiting the property of electron bombardment induced conductivity upon impact of electrons thereon, said input screen comprising a layer of electrical conductive material transparent to radiations of a first wave length region in which said image pickup tube is utilized, a photoconductive layer positioned on said conductive layer on the side thereof facing said target, said photoconductive layer being sensitive to radiations within said first wave length region, a mosaic conductive layer deposited on the exposed surface of said photoconductive layer and opaque to radiations within said first wave length region, a photoemissive layer disposed on said conductive mosaic layer and sensitive to radiations within a second wave length region, an insulating material deposited within the openings of said mosaic conductive and photoemissive layers and opaque to radiations within said first and second wave length regions, a grid member positioned adjacent to said photoemissive layer and between said photoemissive layer and said target, means for illuminating the photoemissive layer with an auxiliary light source of radiations within said second wave length region, means for scanning the surface of said semi-insulating layer of said target with an electron beam to derive a signal from said conductive layer of said target in response to the removal of the charge pattern due to the

conductivity pattern induced in said semi-insulating layer in response to bombardment of said target member with electrons from said input screen.

3. An image pickup tube comprising a vacuum-tight envelope having a photosensitive input screen adjacent one end of said envelope, a target member positioned from said input screen within said envelope, said target comprising a thin conductive layer and a layer of semi-insulating material supported on the surface of said conductive layer opposite from said input screen, said layer of semi-insulating material exhibiting the property of electron bombardment induced conductivity upon impact of electrons thereon, said input screen comprising a layer of electrical conductive material transparent to radiation within a first wave length band in which said image pickup tube is utilized, a photoconductive layer positioned on said conductive layer on the side thereof facing said target, said photoconductive layer being sensitive to radiation within said first wave length band, a mosaic conductive layer deposited on the exposed surface of said photoconductive layer and opaque to radiation within said first wave length band, a mosaic photoemissive layer disposed on said conductive mosaic layer and sensitive to radiations within a second wave length band, an insulating material deposited within the openings of said mosaic conductive and photoemissive layers and opaque to radiation within said first and second wave length regions, an electrical conductive electrode having a plurality of apertures positioned adjacent to said mosaic photoemissive layer and between said mosaic photoemissive layer and said target, said electrode spaced at a distance from said mosaic photoemissive layer such that the distance is substantially the same as the diameter of said apertures, means for illuminating said mosaic photoemissive layer with an auxiliary light source of radiation within said second wave length band, said first and second wave length bands at least partially overlapping, means for scanning the surface of said semi-insulating layer of said target with an electron beam to derive a signal from said conductive layer of said target in response to the removal of the charge pattern due to the conductivity pattern induced in said semi-insulating layer in response to bombardment of said target member with electrons from said input screen.

4. An electron discharge device comprising a target member including a film of material exhibiting the property of electron bombardment induced conductivity above a predetermined value of electron energy, means for generating an electron beam having an average energy below said predetermined value to bombard one surface of said film to establish an equilibrium potential on the surface of said film, an electrically conductive sheet in contact with the opposite surface of said film to maintain the opposite surface at a fixed potential different from said equilibrium potential, an input screen spaced from said target for projecting an image comprising electrons having energies above said predetermined value onto said target member to set up a conductivity image within said film corresponding to the electron image generated by said input screen, said input screen comprising a layer of electrically conductive material transparent to radiation of a first wave length band in which said image pickup tube is utilized, a photoconductive layer positioned on said conductive layer on the side thereof facing said target, said photoconductive layer being sensitive to radiation within said first wave length band, a mosaic conductive layer of a metal deposited on the exposed surface of said photoconductive layer and opaque to radiations within said first wave length band, a mosaic photoemissive layer disposed on said conductive mosaic layer and sensitive to radiation within a second wave length band, an insulating material deposited within the openings of said mosaic conductive and photoemissive layers and opaque to radiation within said first and second wave length regions, a grid member positioned adjacent to said

mosaic photoemissive layer and said target, means for uniformly illuminating said mosaic photoemissive layer with an auxiliary light source of radiation within said second wave length region, means for scanning the surface of said semi-insulating layer of said target with an electron beam to derive a signal from said conductive layer of said target in response to the removal of the charge pattern due to the conductivity pattern induced in said semi-insulating layer in response to bombardment of said target member with electrons from said input screen.

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