Dec. 21, 1965 J. A. SYBELDON 3,225,240

IMAGE TUBE HAVING EXTERNAL SEMICONDUCTIVE LAYER ON TARGET OF WIRES IN GLASS MATRIX

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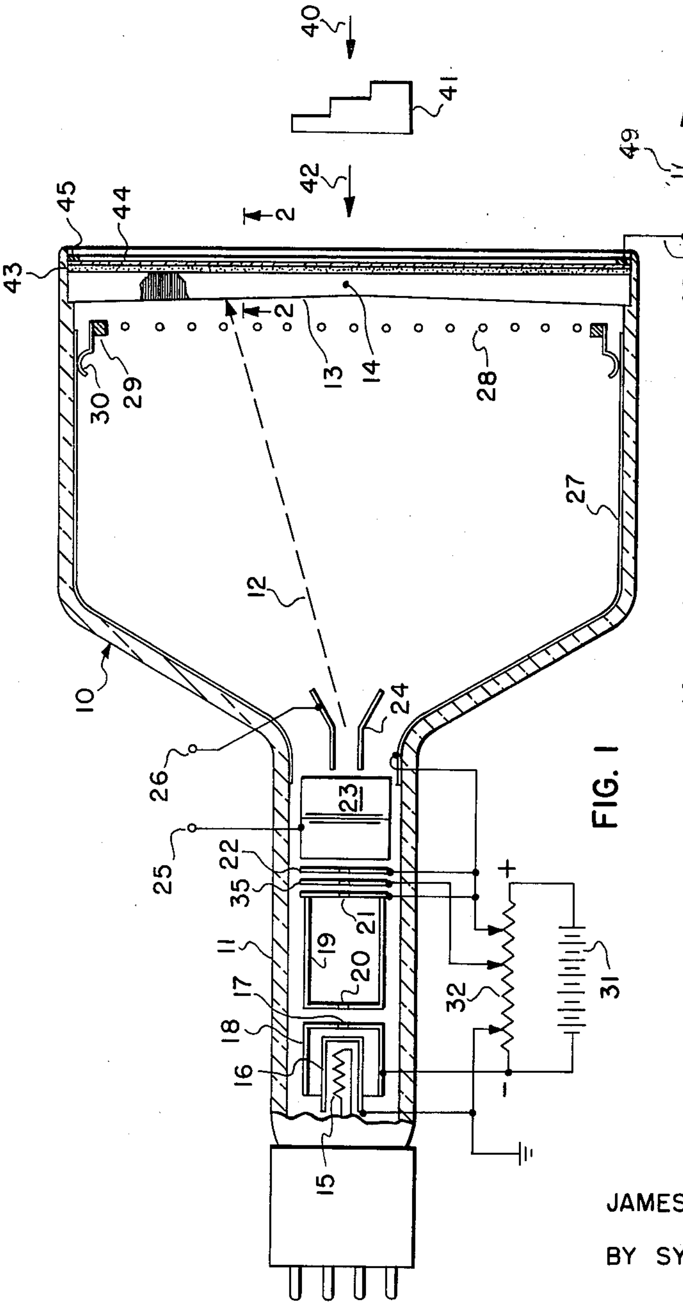

FIG. 1

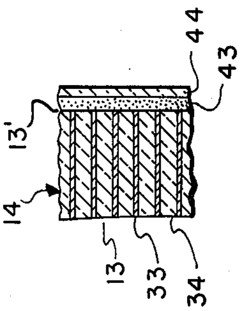

FIG. 2

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IMAGE TUBE HAVING EXTERNAL SEMICONDUCTIVE LAYER ON TARGET OF WIRES IN GLASS MATRIX

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This invention pertains to image tubes that transduce a latent image borne by radiation to corresponding video signals for kinescope display.

A distinctive feature of the image tube constituting the present invention is that the semiconductive layer, usually a photosensitive layer, in which the image is converted to electric signals representative of its intensity variations, is located on its external surface instead of inside the vacuum envelope of the tube as is conventional. Electric coupling between the interior electron beam and exterior semiconductive layer is obtained by way of a glass matrix in which there are embedded a multitude of parallel conductors.

In prior image transducer tubes using low velocity scanning, a photosensitive semiconductive layer is scannned by an electron beam which deposits a charge upon the target surface in an evacuated envelope. The semiconductive layer assumes a uniform potential charge over its scanned surface since the electron emission ratio is less than unity. The semiconductive layer is usually backed by a radiation transparent conductive layer through which the image penetrates. When an image borne by radiation is incident upon the radiation transparent layer and thereby on the semiconductor at the layer interfaces, the impedance of the semiconductive layer is modified at discrete points in dependency upon image intensity variations. This results in a point-by-point variation in the potential on the scanned surface of the semiconductor. Upon the next closely successive scan of the semiconductive or photoconductive layer by the raster swept beam, the potential on the photoconductor surface is lowered to the cathode potential at all points by the impinging electron beam and an equivalent electric charge flows through the semiconductive layer to the conductive layer which is connected to a positive potential source by way of a load resistor. Thus, a video signal is developed in the resistor and the signal may be amplified and displayed in synchronism on a kinescope.

A transducer tube using high velocity scanning may be constructed essentially like the tube just outlined but it is operated at different voltages so that the electron emission ratio from the target is greater than unity. That is, the electron beam strikes the semiconducive layer, which is above cathode potential, at such velocity as to eject electrons from its surface. The ejected electrons are captured by a collector electrode. The transparent conductive layer, on which the semiconductor is deposited, may have a voltage applied to it and thus maintain a difference of potential between opposite surfaces of the semiconductor. A radiation image on the semiconductor makes it conductive and causes a current flow through it to bring the scanned surface toward the potential of the transparent conductive layer. The electron beam, on the next scan will discharge the irradiated areas preferentially and thereby develop a video signal current.

A conventional image transducer that is constructed and operates in either manner just outlined has a number of inherent disadvantages. Among these is that the electron scanning beam impinges directly on the semiconductive layer in which case the layer may be damaged or degraded, especially where high velocity scanning is used.

This often influences resort to scanning with a low energy beam and acceptance of conditions which are other than optimum. Another disadvantage is that the semiconductive layer degrades non-uniformity and exhibits fatigue due to the effect of the vacuum which exists inside the tube. This results in the viewed image not carrying all of the picture information borne by the latent image. A further disadvantage of prior transducer tubes is that they cannot be de-gassed at desirably high temperatures in connection with the evacuation process because many photoconductors will undergo a change of properties or complete destruction at bake-out temperatures that one desires to use.

A further disadvantage of prior art transducers is that with the sensitive layer inside the tube, incoming radiation bearing the latent image may be seriously attenuated by the tube window before it reaches the layer. In addition, when the layer is within the tube and the layer is damaged, or if it is desired to use a layer that is sensitive to different wave energy, it is necessary to break the vacuum in order to get into the tube for changing the layer.

A primary object of the present invention is to overcome the above noted and other disadvantages by provision of an image transducer tube whose sensitive layer is located on the outside of the tube's vacuum envelope. A significant adjunct to this object is that the image which is to be converted to representative electric signals need not traverse the thick radiation permeable window or envelope of the tube and thereby suffer attenuation or dispersion.

A further object of the present invention is to provide an image tube that permits convenient replacement of the sensitive layer without violating the vacuum tight integrity of the tube. An incident to this object is that one basic tube may be used in conjunction with various sensitive materials. That is, a sensitive material having the highest sensitivity to the particular radiation being used may be easily substituted for one that has less than optimum sensitivity. By this means the tube may be readily converted for use with infrared, ultraviolet or visible latent image bearing electromagnetic radiation and for use with phonons or ultrasonic waves.

Another object of this invnetion is to provide an image tube that can be processed under optimum conditions and entirely independent of the effects such processing would have on the sensitive material since the latter may be formed after the tube itself is processed.

A more specific object is to provide an image transducer tube whose window or faceplate comprises an insulating matrix in which there are embedded a multiplicity of electrically isolated feed through wires that couple the electron beam which is inside the evacuated tube with a semiconductive layer that is deposited in a plane normal to the wire ends outside the tube. An incident to this object, and a further object, is to permit contouring the face of the matrix presented inside the tube so that optimum electron optic conditions prevail and to permit selection of the semiconductor qualities and the contour outside the tube that produces optimum radiation optic conditions. In other words, it is contemplated that the matrix and the radiation sensitive material may be controlled independently to minimize or correct for distortion that often occurs in prior tubes.

Achievement of the foregoing and other more specific objects will appear from time to time in the course of the ensuing specification which describes an illustrative embodiment of the invention in conjunction with the drawing in which:

FIG. 1 is a schematic drawing of an image transducer tube constructed in accordance with the principles of the invention; and

FIG. 2 is an enlarged cross sectional fragment broken away from the faceplate of the tube in FIG. 1 in the region of a line corresponding with 2—2 therein.

The tube in FIG. 1 has many of the constructional and operational attributes of the well known vidicon visible light television camera tube although it should be understood that the new tube may be used for transducing latent images carried by radiation in most of the electromagnetic spectrum such as X-rays, ultraviolet or infrared radiation and also phonons and ultrasonic radiation. The invention is also applicable to tubes operating in other modes.

The term semiconductor as used herein is selected as a convenient generic designation for materials whose conductivity changes, usually increases, during irradition with electromagnetic radiation, in which case the material is commonly called a photoconductor, or during irradiation with phonons and ultrasonic waves in which case there is no conveniently available, adequately distinguishing terminology. The semiconductor material may be considered an insulator due to its comparatively lesser conductivity when it is not irradiated. The term radiation is used to indicate any energy, electromagnetic, particle and ultrasonic, to which the chosen semiconductor material is sensitive.

For convenience, utilization of the tube's new features will be described in connection with one designed to operate essentially on vidicon principles. In FIG. 1 is seen the usual evacuated envelope **10** which may be made of metal or glass. In a neck portion **11** of the envelope there are the elements of an electron gun for developing an electron beam shown as a dashed line **12**. The beam may be swept in a raster pattern over the interior face **13** of a faceplate **14** which will be described in detail later. The electron gun comprises a heater filament **15** that is surrounded by a cathode **16** which emits electrons from its closed end when heated. The electrons pass through a hole **17** in a control electrode **18**. The control electrode **18** is usually biased negatively with respect to electron emitter **16** to permit control of the electron beam intensity.

A first accelerating electrode **19** having beam holes **20** and **21** in its ends cooperates with an apertured plate **22** to effect focusing of the electron beam. Electrodes **22** and **19** are at a positive potential with respect to indirectly heated emitter **16** which is at ground potential as shown. Another intermediate less positive electron **35** is also shown. The typical gun elements thus far described create a focused electron beam **12** that may be scanned over the faceplate as indicated above.

Electromagnetic or electrostatic scanning may be employed. In this illustration the beam is scanned or deflected electrostatically by means of plates **23**, for horizontal deflection, and plates **24**, for vertical deflection. Synchronized scanning voltages may be applied to these plates through the agency of their respective external leads **25** and **26**. It is, of course, contemplated that the position of the spot due to beam **12** on the faceplate **14** be synchronized with the modulated beam in the kinescope display tube which the new image tube serves but this television circuitry has been omitted because it may be fundamentally conventional.

The interior of tube envelope **10** may be coated over a limited axial distance with a thin conductive coating **27** of carbonaceous material like that bearing the tradename Aquadag or the equivalent. Coating **27** has a positive potential applied to it which acts to further accelerate the electron beam **12** and to attract any stray electrons or secondarily emitted electrons within the tube. The coating encircles the cone traced by the electron beam **12**. The coating is terminated in a plane transverse to the beam at a wire mesh or screen **28** through which the beam penetrates before impinging on interior surface **13** of faceplate **14**. The mesh may be made of wires on the order of 0.002 inch in diameter and there may be 100 wires per inch. Mesh **28** may be about one-eighth inch from interior faceplate surface **13** and it may be stretched on a supporting ring **29** provided with spring fingers **30** that electrically connect the mesh with conductive coating **27**.

Operating potentials are supplied to the electrodes of tube **10** from a voltage source represented by a battery **31** through a potentiometer **32**. Using the indirectly heated cathode as zero or ground potential, typical voltages applied to the tube are as follows. The control electrode **18** may be adjusted from 0 to −100 volts bias to control the beam current to an appropriate value. Accelerating anode **19** and second accelerating electrode **27** together with its associated mesh **28** may be at about 285 volts. Voltages applicable to components other than those used to develop and accelerate the electron beam will be given later.

The discussion will now be directed to the new faceplate and its associated image transducing elements constituting a target assembly. First, we may observe that the tube is used to examine an object with radiation. The primary radiation represented by arrow **40**, may penetrate or outline an object **41** having varying density, thickness or configuration, or the object may merely reflect radiation. At any rate, some of the radiation that is representative of quality variations in the object proceeds in the form of a latent image in a plane crossing the path of the arrow **42**. This latent image falls upon the faceplate of the tube where it is transduced to corresponding video signals.

The faceplate **14** comprises an insulating matrix of a material **34** which is usually glass in which there are embedded a plurality of fine wires **33** in parallel with each other and the tube axis. The matrix has in the vicinity of 250 wires per lineal inch or 62,500 feedthroughs per square inch. An enlarged fragmentary cross section of the matrix **14** may be seen in FIG. 2. Note that the wire ends terminate flush with the curved glass matrix surface **13** and its opposite face **13′** which is planar in this example. The radius of the surface **13** may be advantageously chosen to agree with the sweep radius of electron beam **12** which results in normal impingement of the beam and some beneficial results incident to choice of a proper landing angle for low velocity scanning as is more fully explained in the instant assignee's Patent No. 2,914,696, Eshbach, dated November 24, 1959. However, the faceplate has special advantage in high velocity scanned tubes.

Surface **13′** may be planar as shown. Thus, the latent image borne by impinging radiation **42** falls on a flat surface as is desirable where radiation consists of parallel rays and distortion is to be minimized. In other words, a flat surface **13′** may be most advantageous where the tube is receiving an image from an effectively infinite focal distance. On the other hand, where the object **41** is near the tube, and so is the source of primary rays **40**, it may be more beneficial to make both surfaces **13** and **13′** concave or other contour to yield optimum optical geometry.

A photoconductive semiconductive layer **43** is deposited on surface **13′** or on the atmospheric side of the tube's faceplate. Superposed on the photoconductive layer **43** is a thin coating **44** of conductive material that must be transparent to the wave or other energy for which the tube is to be employed. In FIG. 1 it may be seen that conductive coating **44** is in electric contact with a metal ring **45** by means of which an electric signal may be taken off via a lead **46**. Thus, it is seen that the faceplate comprises a glass-wire matrix **14** with vacuum on one side and a photoconductive layer **43** and a transparent conductive layer **44** respectively on the atmospheric side thereof. Incoming latent image rays **42** penetrate transparent layer **44** and photoconductive layer **43** the latter of which is conductively connected to the ends of the multitude of feedthrough wires.

Photoconductive layer **43** is composed of a material whose resistance is in the vicinity of 10^{12} ohms/cm.^{3} and which changes its impedance or resistance or becomes more conductive in different regions in accordance with intensity variations in the latent image. Various semiconductors may be used, depending on the type of energy that is sensed. Photoconductive compounds are generally metallic compounds of the halogens or of the oxygen-sulphur sub-group of the periodic table including the metallic halides, oxides and sulphides. Examples are the oxides, sulphides, selenides and tellurides of lead, zinc or cadmium. For high energy radiation like X-rays, the higher atomic number base metal compounds will usually be used. The photoconductive material **43** may be on the order of ten to two-hundred microns thick with the thinner layers being used for low energy radiation like infrared and thicker layers for X-rays. The thickness of the layer also depends on its composition as related to the energy of the radiation.

The radiation transparent conductive film **44** may be a light transmissive substance like tin oxide, tin chloride, or reduced titanium dioxide. Where X-radiation is used the film may be a metallic substance such as nickel. In any case the film chosen should be transmissive to the radiation involved, be conductive and it should protect the semiconductor **43** from the atmosphere if the one used might be easily contaminated by the atmosphere.

The techniques for depositing the semiconductive layer **43** and conductive film **44** may be conventional and need not be discussed in detail except to say that vapor deposition, precipitation or spraying may be employed. It may be seen, however, that the tube **10** may be completely processed at any desired temperature and evacuated with its faceplate matrix **14** sealed in place. Then any desired photoconductive layer **43** and film **44** may be deposited and conductor ring **45** may be sealed in place without endangering the internal tube elements and under the best conditions for depositing the layer and film. Moreover, the layer and film are not subject to deterioration so often incidental to their location in the evacuated interior of the tube.

The arrangement of the tube's faceplate components is such that a voltage may be uniformly applied to the atmospheric side of the photoconductive layer **43** through a circuit which includes the electrode ring **45** and conductive film **44**. The voltage source is symbolically represented by a battery **47** acting through a signal resistor **48**. The potential on the photoconductor **43** is such that it is around twenty-five to one-hundred volts less positive than screen **28** within the tube envelope **10**. Thus, in one practical case, if the mesh potential is 285 volts, as stated earlier, the conductive film may have 260 volts on it, taking ground as the reference potential. These voltages are only illustrative and will vary according to the tube geometry as is known to those versed in the art.

The video signals derived from the tube appear across signal resistor **48** and may be transferred to an electronic amplifier, not shown, and treated in the usual way for ultimate visual presentation of the image on a television tube.

The method of signal generation is comparable with that in television camera tubes of the vidicon type. As shown in FIG. 1, the cathode **16** is operated at ground potential and the mesh **28** and anode film **27** are at about 285 volts. The gun electrode **18** has its potential adjusted to an appropriate negative value for producing the proper constant electron beam current. The other electrodes **19, 22** and **27** have their relatively positive potentials adjusted for desired beam energy and focus. Scanning of beam **12** at television or other rates and in a similar raster pattern may be effected by application of synchronized saw-tooth voltages to the plates **23** and **24** for horizontal and vertical scanning, respectively. An electrical connection is made from the external conductive film **44** through ring **45** to the signal resistor **48**. A positive potential with respect to ground is thus applied to the film by battery **47**.

As electron beam **12** scans the inside surface **13**, or in fact, the ends of the wires **33** in matrix **14**, it deposits electrons on the surface provided that the secondary emission ratio is less than unity. Because of the high resistance of the photoconductive layer **43** very little of the deposited charge can leak from the ends of the wires at the photoconductor interface through the photoconductor to the conductive film **44**. The photosensitive layer **43** then acts as an insulator, essentially, but neglecting dark current. Since little charge leaks during the time of one beam scan over the faceplate its surface **13** and that of the surface of the photoconductive layer on the tube side becomes negatively charged until its potential is substantially that of the electron gun cathode **16**. At this time the beam is retarded to zero velocity at the surface **13** and no more electrons can land.

When this condition is reached, the photoconductor **43** has a potential drop across its surface that is equal to the voltage of battery **47** which may be as high as several hundred volts but is more usually around 25 volts as in this example. This applied electric field will cause a dark current leakage as it maintains the inside surface of layer **43** at cathode potential.

When radiation is absorbed in the photoconductive layer **43**, additional conductivity is produced in a pattern corresponding with the image of the irradiated object or shadow picture. During a scan interval of the electron beam **12**, the photoconductor surface potential will rise, the amount on each incremental area depending on the conductivity. This rise will normally be a fraction of a volt, and when the beam returns to a spot on matrix face **13** that is aligned with a given image element, it will recharge it to cathode potential. Thus, the amount of charge deposited by the electron beam on a picture element via the conductive wires in the matrix will be equal to the current in that element integrated over the frame time. This recharging current must also flow through the signal resistor **48**, since the high resistivity photoconductive material **43** under the electron beam acts as a capacitance during the short time that it takes the beam to deposit a charge. Thus a signal current flows from the outside surface of photoconductor **43** through film **44** and ring **45** and through resistor **48** where a signal voltage is developed. The voltage may be supplied by way of a coupling capacitor **49** to a video preamplifier, not shown, for ultimate synchronous display on a kinescope. Note that the above described method of signal generation uses all of the radiation induced current available over the entire surface, even though the signal is generated by point-by-point scanning.

The new image tube is typically useful in situations where conventional vidicon and image-orthicon television camera tubes are now employed. One significant use is in an X-ray diagnositic system for a purpose similar to that achieved with a fluoroscopic screen. That is, a patient may take the place of object **41**, and when exposed to primary X-radiation **40**, a latent image of the patient's anatomy will be projected on the image tube's photoconductor and converted to video signals for visual display on a kinescope at an X-ray safe viewing station.

The new tube is also useful to display X-ray diffraction patterns such as the well known Laue patterns that are ordinarily recorded on radiographic film in connection with studying the atomic lattice structure of crystalline substances. Of course, various other applications of the image transducer tube in connection with visible, infrared and ultra-violet radiation patterns will also be conceived by those versed in the art.

In summary, a new image transducer tube has been described that features avoidance of image attentuation that is experienced in prior art tubes where the image must pass through a vacuum tight enclosure before reaching the sensitive layer. This advantage is attained by locating the photosensitive layer on the outside of the new tube and electrically coupling it with the evacuated interior by means of a faceplate having a multitude of fine feedthrough wires which the layer contacts intimately. If the photoconductor becomes unstable or it is desired to change its sensitivity to a different region in the electromagnetic spectrum, it may be washed off and replaced without destroying the vacuum in the tube. The configuration of the faceplate's interior can now be designed for optimum coaction with the electron beam while the photoconductor on the exterior can be designed for optimum optical conditions. The photoconductor is now not subject to vacuum deterioration nor to damage by the electron beam and freedom to use almost any desired beam energy is achieved because the beam impinges on the feedthrough wire matrix rather than directly on the photoconductor as was the case heretofore.

Although one embodiment of the invention has been described, such embodiment is to be considered illustrative rather than limiting, for the invention may be variously embodied and its scope is to be determined only by construction of the claims which follow:

It is claimed:

An image transducer tube including an evacuated envelope, electron beam producing means therein, a faceplate means comprising a plurality of fine adjacent wires that are insulated from each other, said faceplate means being mounted vacuum tight in the envelope and having inside and outside surfaces near which opposite ends of the wires terminate, the electron beam being adapted to impinge on the wire ends that are near the inside surface, a semiconductive layer whose electric properties change in different regions in accordance with the intensity variations of a latent image impinging thereon, said layer having an inner surface in contact with the ends of the wires at the outer surface of the faceplate, a radiation transparent conductive film covering the outer surface of said layer, the said film being exposed to the atmosphere and preventing the semiconductor layer from being exposed thereto, and means for sensing variations in electric current flowing from the conductive film due to changes in the electric properties of said semiconductive layer.

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