Oct. 18, 1966 F. H. NICOLL 3,280,357

LIGHT SENSITIVE DEVICE

Filed March 1, 1962

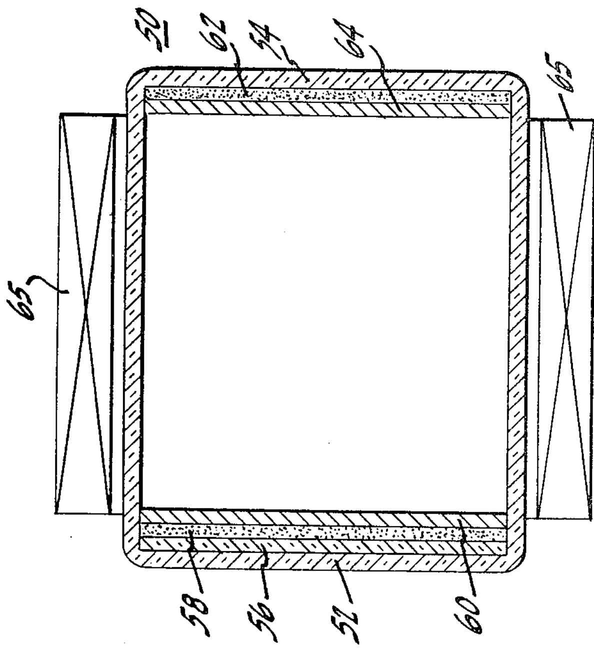

Fig. 3.

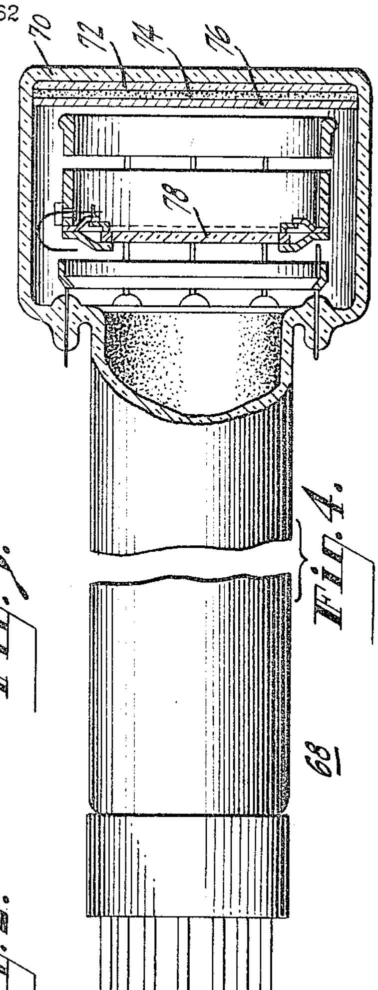

Fig. 4.

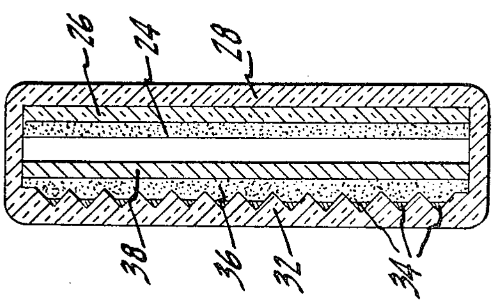

Fig. 2.

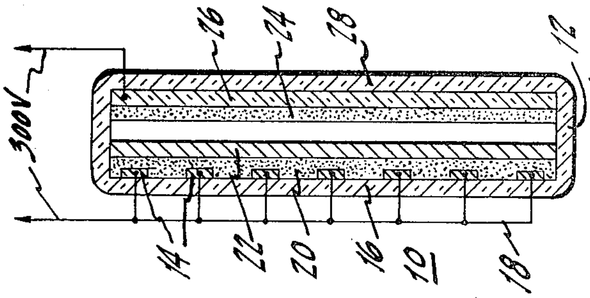

Fig. 1.

INVENTOR.

FREDERICK H. NICOLL

BY

L. A. Larsen

Attorney

3,280,357

LIGHT SENSITIVE DEVICE

Frederick H. Nicoll, Princeton, N.J., assignor to Radio Corporation of America, a corporation of Delaware

Filed Mar. 1, 1962, Ser. No. 176,712
5 Claims. (Cl. 313—65)

This invention relates to light sensitive devices. In particular this invention relates to light sensitive devices utilizing a photoconductor as the light sensitive element.

In the prior art there are many types of light sensitive image devices, e.g. pickup tubes and image tubes. Some of these imaging devices utilize photoemissive materials as the light sensitive element. When one utilizes the photoemissive materials as a light sensitive element, a limited value, e.g. 10^{-5} amps per square centimeter, is about the limit of the electron beam current which can be obtained from the known photoemissive materials. In many imaging devices it is desirable to have larger beam currents per unit of area than that which is obtainable with the use of conventional photoemissive materials.

It is therefore an object of this invention to provide a new and improved light sensitive device.

A further object of this invention is to provide a new and novel light sensitive device characterized in its use of a photoconductor as a light sensitive element to control a copious electron emission.

These and other objects are accomplished in accordance with this invention by providing a photocathode in which a cold electron emitter, e.g. magnesium oxide, is used as an electron emitter with the emission therefrom controlled by means of a photoconductor material.

The invention will be more clearly understood by reference to the accompanying single sheet of drawings wherein:

FIG. 1 is a sectional view of an image amplifying device in accordance with this invention;

FIG. 2 is a sectional view of an embodiment of an image amplifier tube made in accordance with this invention;

FIG. 3 is a sectional view of an image tube made in accordance with this invention; and

FIG. 4 is a partial sectional view of a pickup tube made in accordance with this invention.

Referring now to FIG. 1, there is shown an image tube **10** which comprises an evacuated envelope **12** having a plurality of conducting lines **14** on an image input face **16** of the tube **10**. The envelope may be made of any conventional material, e.g. glass or metal, with the window **16** being transparent to the radiations which it is desired to detect and amplify. The electrically conducting lines **14** may be made of any material such as, for example, evaporated gold which has been deposited through a suitable mask (not shown) on the inner surface of the input window **16**. The conducting lines **14** are spaced apart to permit input radiations to pass therebetween. In this particular embodiment, the conducting lines **14** are electrically connected together and to a lead-in **18**. On the electrically conducting lines **14** there is provided a photoconductive material which has the property of changing its resistance in response to incident radiation. The photoconductive material **20** may be selected for its sensitivity to any desired wave length of radiation, e.g. X-rays, ultra-violet, or visible, and any suitable, known photoconductive material may be used. One example of a photoconductive material which has been found suitable for the visible spectrum is a layer of activated sintered cadmium sulphide or cadmium selenide which is described in detail in U.S. Patent Number 2,765,385 to Thomsen issued October 2, 1956. The layer of photoconductive material **20** may have a thickness of approximately 10 microns. On the photoconductive ma-

terial **20** there is positioned a layer of magnesium oxide **22** which has the property of emitting electrons when a high electric field produces a surface charge on the exposed surface of the magnesium oxide layer **22**.

Spaced closely adjacent to the magnesium oxide layer **22** is a phosphor layer **24** which is supported by means of a transparent electrically conductive coating **26**. The transparent electrically conductive coating **26** is in turn supported upon an output window **28** of the tube **10**. The output window **28** is made of any material which is transparent to the radiations which are produced by the phosphor screen **24**.

The phosphor layer **24** may be made of any suitable material such as willemite, cadmium sulphide or other known cathodoluminescent phosphor material. The transparent conductive coating **26** may be made of any suitable, known electrically conducting transparent material such as evaporated tin oxide.

The magnesium oxide layer **22**, to function as a cold cathode, or a cold electron emitter, preferably is deposited as a porous layer on a suitable substrate. The substrate must be a material which is capable of injecting electrons into the porous magnesium oxide layer, when under the influence of a high applied electric field. A photoconductor, when used as such a substrate, has this desirable property of injecting electrons into the magnesium oxide layer, with the number of electrons injected into any elemental area of the magnesium oxide being controlled by the impedance of the photoconductor in that area.

The porous form of magnesium oxide may, for example, be deposited by burning magnesium in air to form a magnesium oxide smoke and then condensing this smoke on the deposited photoconductor. Alternatively magnesium oxide may be dispersed in an ethyl cellulose binder, and sprayed onto the photoconductor as a layer. The binder is subsequently removed by heating. A layer of approximately 10 to 50 microns thick is deposited by either of the two methods described.

Other materials, for example potassium chloride, may be used as a cold electron emitter. The cold electron emitter material should be a porous insulator with a high secondary emission ratio.

It is believed that the cold electron emitter operates in the following way. Assume that primary electrons, from some external source (not shown), land on the exposed surface of the magnesium oxide. Then, since the secondary emission ratio of the magnesium oxide is greater than unity, this electron bombardment provides a positive charge on the exposed surface of the magnesium oxide. The positive charge "draws" or "pulls" other electrons from the pores of the body of the magnesium oxide layer into the space adjacent the exposed surface of the magnesium oxide where the electrons are controlled by the applied field.

The electrons that are "pulled" from the porous layer **22** come from the electrodes **14** through the photoconductor **20**. Thus, the number of electrons that are "pulled" from an elemental area of the magnesium oxide layer **22** is controlled by the impedance of the photoconductor **20** beneath that elemental area.

The magnesium oxide layer **22** will function as an electron emitter, with the emission controlled by the impedance of the photoconductor, once the cold cathode has started emitting. The starting of the emission may be caused by a radiation, e.g. a light produced by a tungsten source, striking the magnesium oxide, or by some small electron source (not shown) adjacent to the magnesium oxide. The reason that the magnesium oxide layer **22** does not emit electrons when the high electric field, i.e. the field between electrodes **14** and **26**, is first applied, is that the cold electron emission is largely due to a high field produced as a surface charge on the exposed surface of the magnesium oxide layer. This surface charge cannot develop until some electrons leave the exposed surface of the magnesium oxide layer **22**, either as secondary electrons or as photoelectrons. Incident primary electrons, to provide secondary electrons, may be provided by another electron source, e.g. an adjacent hot filament. Alternatively, the original emission may be as a result of ultra-violet radiation impinging on the magnesium oxide layer **22**. Once the emission from the magnesium oxide layer **22** has been started, the emission can be sustained at a level of approximately 10^{-7} amps per square centimeter, or even less. The maintained emission will appear in the form of noise from the device **10**. It should be understood that the cold electron emitter, i.e. the magnesium oxide layer **22**, is different from a photoemissive layer since the maintained emission continues, as long as the field is applied between electrodes **14** and **26**, even if the photoconductor is in the dark.

During operation of the device **10**, a potential difference is applied between all of the conducting lines **14** which are electrically connected together, and the transparent conductive coating **26**. This potential difference may be of the order of 300 v. Since the photoconductor **20** normally operates with a higher sensitivity when D.C. operation is utilized, the potential source is preferably of a D.C. type, e.g. batteries. To utilize this higher sensitivity, even though the magnesium oxide layer **22** will emit a certain number of electrons after it has once been started, the sustaining current required is adjusted, by means of a variable resistor (not shown) in the circuit, so as to be sufficiently small so that light produced by bombarding the phosphor screen **24** with the sustaining electron flow, is negligible as compared to the emission obtainable when operating at the full brightness level. For example approximately 10^{-3} amps per square centimeter, can be obtained when the device **10** is operating at full brightness level. It should be noted that, in the device **10**, the fluorescent or phosphor screen **24** is in close proximity to the magnesium oxide **22** so that high picture resolution is maintained. In other words, the close spacing between the cold emitter **22** and the phosphor screen **24** reduces the possibility of electron spreading between the magnesium oxide cathode **22** and the phosphor anode **24**.

It should be noted that the magnesium oxide layer **22** is deposited on the photoconductor **20**. Thus, the magnesium oxide layer **22** functions both as an electron emitter and as an opaque layer which prevents light feedback from the phosphor screen **24** to the photoconductor **20**.

The operation of the device **10** is such that light falling on the areas of the photoconductor **20** causes a reduction of impedance in each elemental area of the photoconductor. This decreased impedance, in turn, allows more current to flow from the electrodes **14**, through each of the excited elemental areas of the photoconductor **20** through corresponding elemental areas of the cold cathode emitter **22** to corresponding elemental areas of the phosphor screen **24** where light is produced.

When the device **10** is in the dark, and since the resistance of the photoconductor is high, the output light of the phosphor layer **24** is very small. However, since a thin photoconductive layer **20** is used, it is possible to have some current flow through the photoconductor directly over each of the conducting lines **14**. This current flow will show up as bright lines on the phosphor screen **24**. Thus if one desires an oscillograph type display, the conducting lines **14** may be replaced with a conducting grid which will result in an image display on a graph-like structure.

Referring now to FIG. 2 there is shown an embodiment of this invention wherein the input window comprises a glass surface **32** corrugated on its inner surface and supporting a plurality of electrically conducting lines **34**. Each of the conducting lines **34** is positioned in the valley between two of the corrugations of the input window **32**. Covering the conducting lines and filling the exposed surface of the corrugated glass **32** is a layer of photoconductive material **36**. On the layer of photoconductive material **36** is a layer of magnesium oxide **38**. The remainder of the tube may be the same as that described in connection with FIG. 1.

During operation of the devices shown in FIG. 2 an input image from a scene to be reproduced, excites the photoconductor which will produce a copious electron emission from the magnesium oxide layer **38** which will produce a bright visible output image. In this embodiment, no bright lines will be displayed in the light output due to the fact that the field across the photoconductive layer **36** above each of the conducting lines **34** is substantially reduced by virtue of the greater thickness or depth of the photoconductive material **36** over each of the conducting lines. The deeper parts of the photoconductor will be more insulating due to lack of penetration by the incident light.

Referring now to FIG. 3, there is shown an embodiment of this invention as used in an image tube **50**. The image tube **50** comprises an input window **52** and an output window **54**. Positioned on the input window **52** is a light transparent electrically conducting layer **56** which may be made of a material such as tin oxide. Positioned on the transparent conducting layer **56** is a layer of photoconductive material **58**. On the photoconductive layer **58** is positioned a layer of magnesium oxide **60**.

On the output window **54** there is provided a phoshor screen **62** having a light opaque, electron transparent, electrically conductive layer **64** thereon. The phosphor screen **62** may be made of any conventional materials while the light opaque, electron transparent layer **64** may be thin (e.g. 1,000 Angstrom units), and made of a material such as aluminum. Positioned around the image tube **50** is a focusing coil **65**.

Thus, the embodiment shown in FIG. 3 differs from the earlier embodiments in that a continuous light transparent electrically conductive layer is used under the photoconductor **58**. Also, the output phosphor screen **62** is positioned a substantial distance from the electron emitting magnesium oxide layer **60** and a focussing means, as represented by the magnetic focussing coil **65**, is used to maintain the electrons in focus in their transit through the tube.

It should be understood that the embodiment shown in FIG. 3 may use additional electrodes to provide an electric field directly adjacent the exposed surface of the magnesium oxide, to attract the electrons from the pores of the magnesium oxide layer **60**. The need for these additional electrodes will depend upon the electrode spacing and field produced adjacent to the magnesium oxide layer **60**. A conventional wire mesh screen, or conventional annular wall coating electrodes (not shown) could be utilized to produce the desired field.

Referring now to FIG. 4, there is shown an embodiment of this invention as used in an image orthicon type pickup tube. The image orthicon type tube **68** includes a photocathode in accordance with this invention. The photocathode is on an input window **70** which supports a transparent conductive coating **72**. On the transparent conductive coating **72** is a layer of photoconductive material **74**. On the layer of photoconductive material **74** there is provided a layer of magnesium oxide **76**. Spaced from the magnesium oxide layer **76** is a conventional charge storage target **78**. The charge storage target **78** may be made of any conventional material such as a thin membrane of glass or a thin semi-conductive material such as magnesium oxide. The balance of the tube **68** may be a known image orthicon operated in a known manner, such as described for example, in U.S. Patent Number 2,942,132 issued to Rotow et al. or U.S. Patent 2,433,941 to Weimer.

In general, an image strikes the photoconductor which controls the electron emission from the magnesium oxide layer **76**. The electrons thus emitted are accelerated onto the target 78 where the image is stored and is subsequently read off by an electron beam to provide output signals from the tube.

Thus, applicant's invention may be utilized in any type of light sensitive device and may provide an extremely thin tube such as shown in FIGS. 1 and 2. An advantage of this thin tube is that cathodoluminescent phosphor materials may be used which are considerably more efficient than the solid state electroluminescent materials. Assuming that the photoconductor has the same area as the magnesium oxide cathode, then the ratio of lumens input to lumens output can provide gains of 50 times or better.

I claim:

1. An image sensitive device comprising an evacuated envelope, a light transparent support within said envelope, light transparent electrode means positioned on said support, said electrode means comprising a plurality of spaced conducting lines electrically interconnected, photoconductive material in contact with said electrode means and with said support between said lines, said material being thinner in areas of contact with said lines than in areas of contact with said support, a cold electron emitter in contact with said photoconductive material, and means spaced from said emitter for receiving electrons from said emitter.

2. An image sensitive device as in claim 1 wherein said cold electron emitter comprises porous magnesium oxide.

3. An image sensitive device as in claim 1 wherein said means for receiving electrons comprises a cathodoluminescent phosphor screen.

4. An image sensitive device comprising an evacuated envelope, said envelope including a wall portion made of light transparent material, the inner surface of said

wall portion being corrugated to provide valleys, each valley being formed between two adjacent corrugations, conductive material in each of said valleys forming a conductive line therein, said conductive material being spaced below the plane of the peaks of said corrugations, a layer of photoconductive material over said corrugated surface and over said lines of conductive material, said layer of photoconductive material being thicker at the regions thereof over said lines of conductive material than at regions thereof over the other portions of said corrugated surface, a layer of porous magnesium oxide over said layer of photoconductive material and adapted to emit electrons, and means spaced from said layer of photoconductive material responsive in image formation to electrons emitted from said layer of magnesium oxide.

5. An image sensitive device as in claim 1 wherein said means for receiving electrons comprises a charge storage target.

References Cited by the Examiner

UNITED STATES PATENTS

2,487,665	11/1949	Morton et al.	313—65
2,960,617	11/1960	Lodge et al.	315—10
2,970,219	1/1961	Robert et al.	313—65 X

OTHER REFERENCES

"Thin Film Field Emission" by Malter, Physical Review, vol. 50, pages 48 through 58, Apr. 23, 1936.

HERMAN KARL SAALBACH, *Primary Examiner.*

GEORGE N. WESTBY, *Examiner.*

S. CHATMON, Jr., *Assistant Examiner.*