Oct. 16, 1962 F. KOURY 3,059,118

LIGHT AMPLIFICATION AND STORAGE DEVICE

Filed Dec. 28, 1956 3 Sheets-Sheet 1

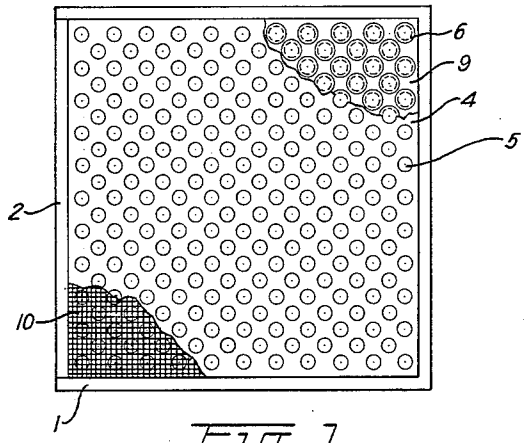


Fig. 1

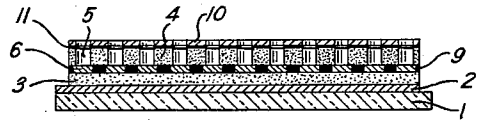


Fig. 2

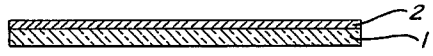


Fig. 3



Fig. 4

INVENTOR
FREDERIC KOURY

BY Lawrence Buss
ATTORNEY

LIGHT AMPLIFICATION AND STORAGE DEVICE

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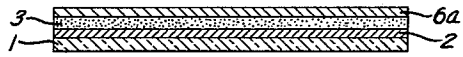


Fig. 5

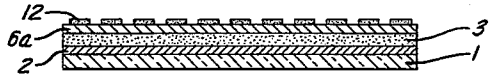


Fig. 6

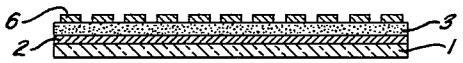


Fig. 7

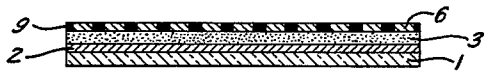


Fig. 8

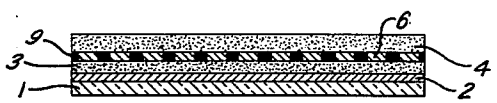


Fig. 9

INVENTOR
FREDERIC KOURY
BY Lawrence Brown
ATTORNEY

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LIGHT AMPLIFICATION AND STORAGE DEVICE

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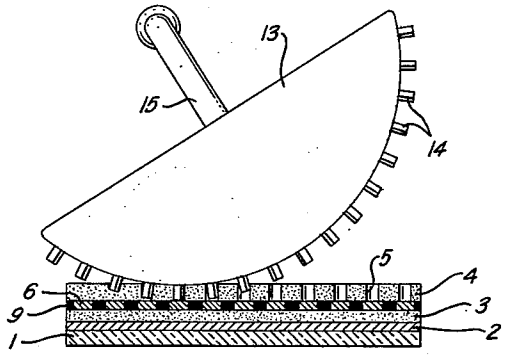


Fig. 10

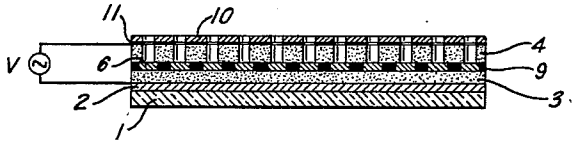


Fig. 11

INVENTOR
FREDERIC KOURY
BY Lawrence Brun
ATTORNEY

United States Patent Office 3,059,118 Patented Oct. 16, 1962

3,059,118

LIGHT AMPLIFICATION AND STORAGE DEVICE

Frederic Koury, Lexington, Mass., assignor, by mesne assignments, to Sylvania Electric Products Inc., Wilmington, Del., a corporation of Delaware

Filed Dec. 28, 1956, Ser. No. 631,131
6 Claims. (Cl. 250—213)

This invention relates to photoconductors, and especially to methods and devices in which photoconductors are used in combination with electroluminescent devices in order to obtain amplification of light or of similar radiation. In particular, the invention relates to a device for amplifying the brightness of an optical image, or for acting as a solid stage storage device for use as a read-out for computors, data-processing equipment and the like.

Light-amplifying devices utilizing a layer of photoconductive material in series with an electroluminescent layer are already known. However, in such prior devices the incident light did not generally penetrate the entire photoconductive layer and hence the change in resistance due to the photoconductivity was limited. Photoconductivity being a surface effect, the main mass of the layer remained unchanged in its resistance.

By my invention, however, the photoconductive layer is made foraminous, that is, with numerous holes in it, into which light passes to be reflected back and forth until absorbed. Preferably, the holes extend entirely through the layer, from one side to the other, with an electrical connection on each side. There is thus a continuous surface path between the electrodes, and the conductivity of the inside surface of the holes, and hence of the entire path from one side of the layer to the other, is directly affected by incident light.

When a photoconductive layer is used in series with an electroluminescent layer, light amplification can be obtained, because a small amount of light incident on the photoconductive surface can, by changing the resistance of the latter, control the emission of a larger amount of light from the electroluminescent layer.

The light from the electroluminescent layer itself may feed back onto the photoconductive layer and thereby affect its operation. If the light from the electroluminescent layer is prevented from reaching the photoconductive layer, for example by the interposition of an opaque screen interposed between the two, then electroluminescence will occur only while the photoconductive surface is irradiated by incident light.

If, however, sufficient light from the electroluminescent layer is allowed to reach the photoconductive layer, then the electroluminescence, once started, will continue until the voltage is removed from the device, or until the luminescence is electrically quenched in some other manner, the electroluminescent light acting to maintain the photoconductive layer in a low resistance state.

On the other hand, if the amount of light reaching the photoconductor from the electroluminescent layer is too small to maintain the equilibrium voltage drop across the electroluminescent layer at a value sufficient for electroluminescence, in the absence of light incident from external sources, it can nonetheless slow the rate at which the voltage across the layer decreases from its value in the presence of incident light, to its value in the absence of such light, and thus slow the decay of the luminescence after exposure.

By varying the applied voltage or the intensity of the incident or triggering light, the time during which the device will continue to emit light can be varied from a few microseconds to a period of days. This period is called the storage time.

The decay period can also be changed by varying

the frequency of the applied voltage, because the electroluminescent layer is capacitative, and hence takes more current at the high frequencies, for a given voltage. The increased current flows through the photoconductive layer, increasing the voltage drop across it and decreasing that across the electroluminescent layer.

The storage effect is useful in computer circuits, read-out circuits and the like, and also because increasing the duration of the light emission increases the total light output for a given triggering impulse.

In order to facilitate the use of my device as a light amplifier, a small conducting disc can be used on the electroluminescent layer at the "bottom" of each hole, the word "bottom" being here used merely as meaning the part of the hole nearest the electroluminescent layer. The disc can be of slightly larger diameter than the inside of the hole, in order to insure good contact with the photoconductive material. Thus when incident light falls on one of the holes, the resistance in series with the disc will be lowered, and the electroluminescent layer will emit light from a region in register with the hole, that is, with the disc.

If light falls on some holes but not on others, or if the intensity of light falling on the holes is different, an electroluminescent image will be produced.

Inasmuch as the photoconductive coating, if of the usual type, requires heating or sintering, it would be difficult to apply over a coating of phosphor in inorganic dielectric, because the latter would be destroyed by the sintering, if done after the layer was in place. However, by embedding the phosphor in a ceramic dielectric, the sintering can be done without harming the dielectric, and in addition, the permanent alignment of the various parts is facilitated.

Other objects, advantages and features of the invention will be understood from the following specification taken in connection with the accompanying drawings in which:

FIGURE 1 is a plan view of one embodiment of the invention;

FIGURE 2 is a profile cross-section of the same device; and

FIGURES 3 to 11 inclusive, show the device in various stages of manufacture.

In FIGURES 1 and 2 the glass base plate 1 carries a surface layer of a transparent conductive coating 2, which can be one of the type now well-known in the art, such as the stannous chloride coating shown in United States Patent 2,624,857, issued January 6, 1953, to Eric L. Mager. Over the coating 2 is an electroluminescent layer 3, which can consist of an electroluminescent phosphor embedded in a solid dielectric material. The phosphor can be of a type well-known in the art, for example, the copper and lead activated zinc sulfide shown in United States Patent 2,728,730, issued December 27, 1955, to Keith H. Butler and Horace H. Homer, and the dielectric coating in which the phosphor is embedded can be, for example, of the ceramic or glass type shown in copending application Serial No. 365,617, now abandoned, filed July 2, 1953, by Richard H. Rulon.

Over the electroluminescent layer 3 is a layer 4 of photoconductive material containing numerous cylindrical holes 5, and at the bottom of each hole is a circular conducting disc 6. The diameter of the disc 6 is slightly larger than the diameter of the hole 5 in order to make good contact with the photoconductive material 4 at the bottom of the hole 5. The photoconductive material 4 may be copper-activated cadmium sulfide, which is a well-known material of that type, or may be of some other suitable material. The discs 6 may be formed of transparent conductive coating, such as the material used in coating 2, or if no interaction between the light from electroluminescent layer 3 and the photoconductive layer

4 is desired, may even be opaque, for example of a reflecting metal such as aluminum.

An opaque coating **9**, which may be of black enamel, for example, covers the area between the disc **6**, in order to prevent short-circuiting of one disc **6** to another through photoconductivity produced on the bottom of the photoconductive layer **4** by light from the electroluminescent layer **3**, and also to prevent halation due to internal reflections in the electroluminescent layer.

The opaque layer **9** can be made of other suitable material, if desired, and if the thickness of the photoconductive layer **4** is sufficient to prevent transmission of light therethrough, the opaque layer can be omitted, insofar as optical halation is concerned, although in that case there will be some electrical leakage between discs **6**, due to the conductivity of the bottom of the photoconductive layer **4** when stray light from the electroluminescent layer **3** falls upon it. That may tend to obscure the image somewhat.

A wire screen **10** of about 200-mesh is placed over the outside surface of the photoconductive layer **4**, and is cemented thereto with conductive silver paint **11** of the air-fired type.

The glass base plate **1** can be of any convenient size, for example, 10 inches by 10 inches, with a thickness sufficient for mechanical strength, for example, about one-eighth inch, although a thickness as small as 0.06 inch has been used. The thickness of the conductive coating **2** is difficult to measure, because of its extreme thinness, but will be determined by conditions of application. It will generally be less than 0.001 inch, and we have used a thickness sufficient to give a resistance of 100 ohms per square, that is a resistance of 100 ohms measured between two opposite sides of a square, one of whose surfaces is coated with the material. Since the length and width of the resistive path will be the same for any coated square, with the same kind and thickness of coating, the resistance will be the same for all squares and is used as a standard unit.

An electroluminescent layer **3** of a thickness of about 0.0025 inch has been used, although the thickness is not critical, and will vary with voltage to be applied.

The layer **9** of black enamel can be of 4 to 6 mils (thousandths of an inch) thickness. The enamel layer **9** will generally have a thickness greater than that of the conductive discs **6**, but the photoconductive layer **4** will accommodate itself to the difference in thickness of the components of the composite underlying layer **6**, **8**. A photoconductive layer of the thickness of about 6 to 8 mils has been used, with a diameter of 0.040 inch or 0.017 inch for the holes, the discs having a diameter respectively, of 0.046 inch or 0.023 inch, in order to be slightly larger than the holes. A hole diameter of 0.017 inch is about right to produce a picture of about the same structure as the present television screen, but any suitable diameter can be used.

The wire screen **10** is about 400 mesh standard, of nickel wire, and has a light transmission of 80%.

The voltage used across the device of the foregoing dimensions was 300 to 500 volts, and the amplification ratio was 60 to 1. Other suitable voltages can be used.

The foregoing dimensions can be varied widely and are not critical, being given merely as illustrative examples.

A device according to the invention can be made by beginning with a glass plate **1** coated with a transparent conductive coating **2** of stannous chloride or the like, as shown in FIGURE 3, and applying to it an electroluminescent layer **3** of phosphor particles embedded in a ceramic dielectric, giving the result of FIGURE 4.

The phosphor-dielectric layer **3** shown in FIGURE 4 can be applied, for example, as in copending application Serial No. 365,617, now abandoned, filed July 2, 1953, by Richard M. Rulon, that is by sifting a mixture of about 10% by weight phosphor particles and 90% glass frit, of a composition described in said application, onto the conductive coating **2** and heating to a temperature of about 700° C. for about six minutes. The heating can be done in an oven, and immediately on removing the piece therefrom, while the coating **3** is still hot as between about 600° C. and 700° C., the electroluminescent layer **3** is sprayed with a solution of stannic chloride in mixed solvents, in the proportion of about 1 gram of $SnCl_4 \cdot (5H_2O)$, 0.5 cc. of formaldehyde solution (37% HCHO in water) and 0.8 cc. of ethyl alcohol (acetone-denatured).

The transparent conductive coating **6***a*, as shown in FIGURE 5, must be broken up into numerous separated conductive discs **6** as shown in FIGURE 7. This can be done with the use of Eastman Kodak "photo-resist" material, which is a photosensitive lacquer. The photo-resist lacquer is applied over the transparent conductive coating **3** and is then exposed to ultra-violet light in the usual manner, say for two to ten mintues, through an opaque foraminous mask having numerous circular holes. Then the standard commercial photo-resist developer is applied to the lacquer, removing it except in circular "dot" areas **12**, where the ultraviolet light reaches the layer through the holes in the mask. The device in this stage is shown in FIGURE 6.

The lacquer dots are then used to protect the portions **6** of transparent coating **62** under the dots while the remainder of the coating **62** is removed by a chemical treatment. For example, metallic zinc dust can be spread over the coating and a 20% solution by volume of concentrated hydrochloric acid in water can be applied to the coating **62** to remove it where it is not protected by the lacquer dots **12**. The photo-resist lacquer dots **12** can then be removed by dissolving them in acetone or similar solvent, leaving only the transparent conductive discs **6**, **6**, on the electroluminescent coating **3**, as shown in FIGURE 7.

In FIG. 8, the area between the dots is shown coated with an opaque coating **9**, which can be a black enamel or other suitable material applied through a suitable silk screen which masks the dots but exposes the surface between the dots, in accordance with the usual silk screen techniques.

A coating of graphite can be applied as the opaque coating, if desired, although in that case there may be some electrical conductivity between discs **6**, and an inert atmosphere such as nitrogen, or a slightly reducing atmosphere may have to be used to prevent oxidation.

When the glass piece **1** is of window glass or lime glass, one suitable enamel for coating it is a soft-glass glaze composed of a flux of 70% red lead, 21.5% silica, 2.5% boric acid, 6% aluminum hydrate and pigment equal to about 20% of the total weight of the glaze. The pigment can be about 25% cobalt oxide, 25% manganese dioxide, 15% iron oxide and 35% titanium dioxide. Such a black enamel is described in U.S. patent application, Serial No. 559,864, filed January 18, 1956, by F. A. Loughridge et al., in which he uses it with potter's flint and L-clay to adapt it to use on Pyrex or borosilicate glass.

A coating or photoconductive material, for example, of copper-activated cadmium sulfide is applied over the dots **6** and the opaque coating **10**. The device at this stage is shown in FIG. 9. The photoconductive powder can be suspended in a solution of ethyl cellulose. For example, about 6% by dry weight of N-200 ethyl cellulose can be dissolved in a solvent composed of 9.9% by weight dibutyl phthalate, 80.5% xylol and 4% butanol (butyl alcohol). "N-200" ethyl cellulose is a type having a viscosity of 200 centipoises per second in standard solution, and having an ethoxy content between 46.8% to 48.5%. About 10 cc. of the above solution is diluted with about 90 cc. of xylol, and 20 grams of copper-acti-

vated cadmium sulfide is added per 100 cc. of the solution.

After application of the suspension, it is dried, that is the xylol is evaporated, and a series of holes is made in the layer, each hole being in register with, and preferably of slightly smaller diameter than, one of the conductive discs **6**. The holes can be punched through the layer **4** one by one, with a needle, if desired, or they can be pressed out as in FIG. 10, by a roller **13** having a series of pins **14** arranged to come in register with conductive dots **6**. The roller can have a handle **15**.

The dots **6** can also be applied in another manner, that is by silk screen techniques. A screen having masking dots of a size just sufficient to cover conductive disc dot **6** can be placed over the conductive discs **6** and the opaque area **8**, that is over the top of the device when in the stage shown in FIG. 8, the masking dots being in register with the discs **6**, and the suspension of photoconductive material applied through the silk screen, then dried and baked. This can be repeated several times until a layer **4** of the desired thickness is built up. Instead of baking between each step, the material can merely be dried between each step and the baking done after the layer **4** is built up to a desired thickness.

A thin wire mesh **10** is then coated with a layer **11** of silver paint of the air-drying type and pressed over the photoconductive layer **4**, the silver paint acting as a conductive cement to bind the mesh **10** to layer **4**. The mesh **10** can have a transmission of 80% or more so that it will not greatly reduce the amount of light entering the holes **5**. A profile section of the completed device is shown in FIGS. 2 and 11, with a plan view, with the wire mesh **10** broken away for clarity except at one corner, as shown in FIG. 1.

In operation a voltage V is connected between electrodes **2** and **10**, as indicated in FIG. 11. The voltage is insufficient to produce appreciable luminescence when the photoconductive layer **4** is in the dark (or at a desired ambient background level of illumination), yet sufficient to produce luminescence when a predetermined intensity of light falls on the photoconductive layer **4**.

An image can be focussed on the top of the device, so the light from it enters the holes, and the image will appear in amplified form on the electroluminescent layer **3**, which can be viewed from the bottom through the glass plate **1**, in FIG. 11. Ordinarily, the device will be used vertically, rather than horizontally as shown in the FIG. 11. Then light can fall on the photoconductive material **11** on one side and appear in amplified form on the other side.

In order to facilitate the making of connections to the transparent conductive layer **2**, it is generally preferable to have the glass plate **1** and its conductive coating **2** extend outwardly beyond the electroluminescent coating **3** and other coatings, as shown in FIGS. 1 and 2, although it is not so shown in FIGS. 3–11.

Although the device has been generally described above in connection with its excitation by incident light waves, it can be used with various forms of radiation, including cathode rays or other types of electron beams.

The specific embodiment is described by way of illustration and not by way of limitation, and various modifications and alterations will be apparent to those skilled in the art, without departing from the spirit and scope of the invention.

What I claim is:

1. An information-displaying device comprising an electroluminescent layer, a series of separated conductive areas thereover, and a foraminous photoconductive layer thereover having holes in register with said separated conductive areas.

2. An information-displaying device comprising a transparent conductive layer, an electroluminescent layer thereover, a series of separated conductive areas over said electroluminescent layer, a foraminous photo-conductive layer thereover having holes in register with said separated conductive areas, and an electrical connection to the outer surface of said photoconductive layer.

3. An information-displaying device comprising a transparent conductive layer, a layer of electroluminescent phosphor in a ceramic dielectric material thereover, a series of separated conductive areas over said electroluminescent layer, a sintered foraminous photoconductive layer thereover having holes in register with said separated conductive areas, and an electrical connection to the outer surface of said photoconductive layer.

4. An information-displaying device comprising a transparent conductive layer, an electroluminescent layer thereover, a series fo separated transparent conductive areas over said electroluminescent layer, a layer of opaque material covering the area between said separated transparent conductive areas, a foraminous photoconductive layer thereover having holes in register with said separated conductive areas, and an electrical connection to the outer surface of said photoconductive layer.

5. An information-displaying device comprising an extended transparent conductive layer, an electroluminescent layer thereover, a series of separated conductive areas over said electroluminescent layer, a foraminous photoconductive layer thereover having holes in register with said separated conductive areas, at least some of the separated conductive areas being in electrical contact with the photoconductive material around the surface of the holes, and an electrode connected to the outer surface of said photoconductive layer.

6. An information-displaying device comprising an extended transparent conductive layer, a layer of electroluminescent phosphor in a ceramic dielectric material thereover, a series of separated conductive areas over said electroluminescent layer, a foraminous photoconductive layer thereover having holes in register with said separated conductive areas, at least some of the separated conductive areas being in electrical contact with the photoconductive material around the surface of the holes, and an electrode connected to the outer surface of said photoconductive layer.

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