March 24, 1970 R. D. STEWART 3,502,885

NON-COPLANAR ELECTRODE PHOTOCONDUCTOR STRUCTURE AND ELECTROLUMINESCENT-PHOTOCONDUCTOR ARRAY

Filed Aug. 21, 1967

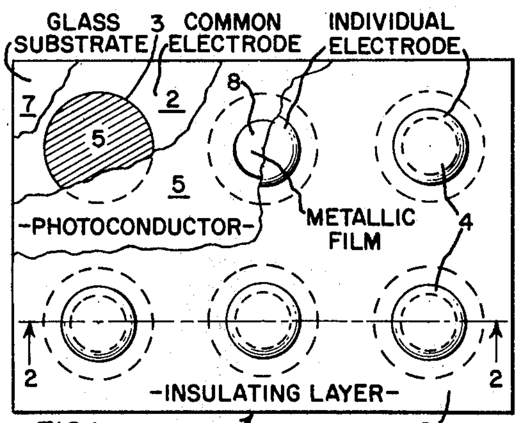

FIG.1

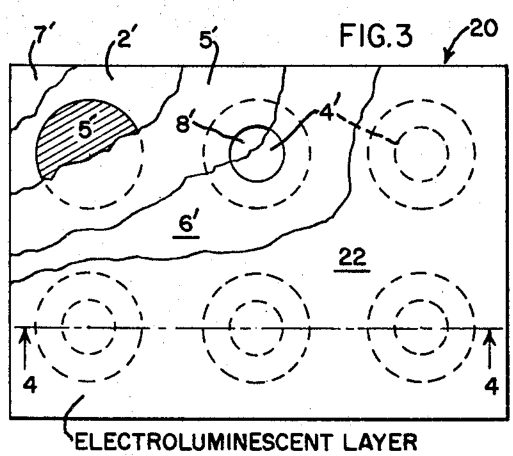

FIG.3

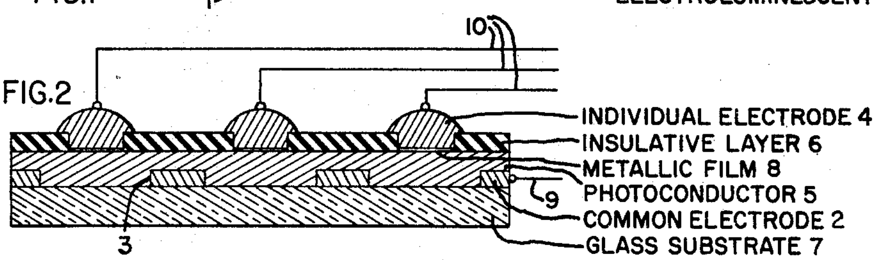

FIG.2

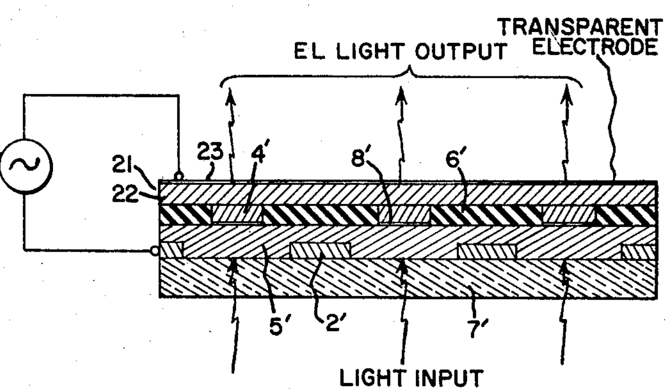

FIG.4

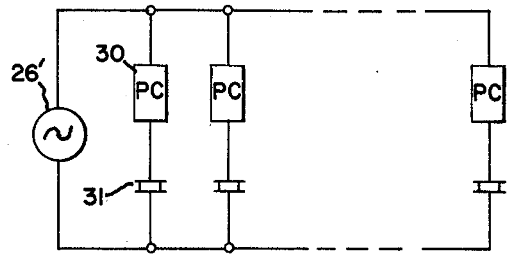

FIG.5

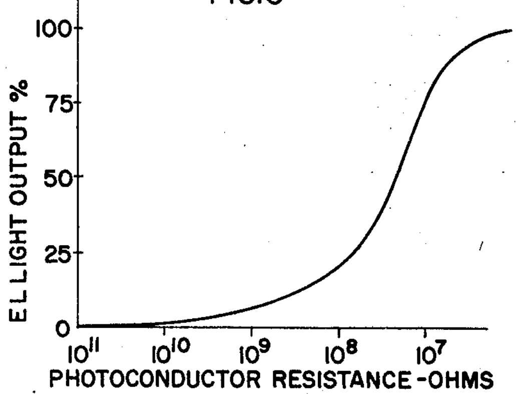

FIG.6

INVENTOR:
RICHARD D. STEWART,
BY Marvin D. Goldenberg
HIS ATTORNEY.

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NON-COPLANAR ELECTRODE PHOTOCONDUCTOR STRUCTURE AND ELECTROLUMINESCENT-PHOTOCONDUCTOR ARRAY

Richard D. Stewart, Camillus, N.Y., assignor to General Electric Company, a corporation of New York

Filed Aug. 21, 1967, Ser. No. 662,135

Int. Cl. H01j *31/50, 39/12*

U.S. Cl. 250—213 8 Claims

ABSTRACT OF THE DISCLOSURE

A photoconductor structure that is electrically compatible with electroluminescent panels and provides efficient detection of applied optical energy. The structure includes a pair of non-coplanar concentric electrodes with the photoconductor material extending therebetween, one electrode provided with an aperture through which said optical energy is admitted. In a further embodiment, the photoconductor structure is fabricated in array form integral with an electroluminescent array to provide optical amplification or conversion.

BACKGROUND OF THE INVENTION

Field of the invention

The invention relates to photoconductor structures in array form and, further, to the use of such photoconductor structures in combination with electroluminescent cells to form a solid state optical amplification or conversion device.

Description of the prior art

Photoconductor structures have in the past been fabricated principally with either a coplanar or parallel plane electrode configuration. In the coplanar structure, interdigital electrodes are normally employed, either overlaying or underlaying the photoconductive material. In the parallel plane electrode structure, the photoconductive material is sandwiched between an electrode pair. Neither of these configurations has been found to be completely satisfactory when construction of the photoconductor is integral with an electroluminescent array to control the light output thereof in an optical amplification or a conversion device. The limitations become more pronounced for high resolution requirements, e.g., above ten lines per inch. For such operation the photoconductors are employed to apply a source voltage across the electroluminescent cells as a function of a light input to thereby control the light emission. To effectively perform this function, the photoconductor structure must have photoconductive characteristics which provide sufficiently large differences in conductivity between light and dark conditions. As a related constraint, the structure must be capable of supporting relatively large voltages for dark conditions, so that for these conditions sufficiently low voltage levels will exist across the electroluminescent cells. In addition, it is desirable that the photoconductor structure exhibit adequate sensitivity to applied low light levels. Finally, it is desirable that the photoconductive structure lend itself to an easy fabrication when integrally combined with an electroluminescent array.

With respect to the coplanar electrode embodiments, it is difficult to make contact between the electroluminescent array and the interdigital electrodes because of the limited area defined by these electrodes. This fabrication problem is still more acute where the photoconductive material is deposited over the interdigital electrodes making the electrodes inaccessible from the top side. A further limitation exists for this latter embodiment since, to a substantial degree, applied light is blocked by the electrode structure so that only the photoconductive material between the digits actively contributes to the photoconductor operation.

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Although optical efficiency is improved for the embodiment in which the electrode structure overlays the photoconductive material, a suitable process is not available for finely depositing conductive material on a polycrystalline photoconductor so as to obtain a high resolution structure.

In both of the above referred to embodiments electrical conduction through the photoconductor is close to the surface, and unwanted surface effects are in evidence which act as shunt resistances in parallel with the photoconductor resistance. As such, these shunt resistances limit the voltage across the photoconductor.

The parallel plane electrodes structure, although exhibiting a relatively good optical efficiency, exhibits a capacitance between the parallel electrodes that is large relative to the capacitance of standard electroluminescent cells, which require A-C voltage sources. Hence, the admittance of the photoconductor in the dark state remains relatively high, as does the minimum voltage across the electroluminescent cells. Therefore, the electroluminescent cells are not readily switched between light and dark states. This capacitance cannot be adequately reduced by further separation of the electrodes because the photoconductor thickness then precludes effective light penetration.

SUMMARY OF THE INVENTION

It is accordingly an object of the invention to provide a novel photoconductor structure exhibiting a wide impedance variation between conditionts of total exposure and nonexposure by means of a readily achieved fabrication.

It is another object of the invention to provide a novel photoconductor structure which has a conveniently accessible electrode structure for making direct external connection thereto.

It is still another object of the invention to provide a novel photoconductor structure that is electrically compatible with conventional electroluminescent cells.

It is a further object of the invention to provide a novel photoconductor structure having a non-coplanar electrode arrangement exhibiting a capacitance that is low relative to that of the electroluminescent structure.

It is yet another object of the invention to provide a novel photoconductor structure which exhibits an efficient detection of applied optical energy.

It is still a further object of the invention to provide a novel electroluminescent-photoconductor array employing a photoconductor structure as above set forth, that can be readily fabricated in integral form and which has improved optical properties over that known to the art.

It is yet another object of the invention to provide a novel electroluminescent-photoconductor array having properties as above described that can be readily fabricated to yield a high resolution display.

These and other objects of the invention are accomplished by employing a photoconductor structure which utilizes a non-coplanar, concentric arrangement of electrodes. The photoconductor structure includes a first apertured electrode and a further electrode of dimensions smaller than the aperture of said apertured electrode concentrically arranged with the apertured electrode and spaced therefrom by a photoconductive material sandwiched between the electrodes. The entire structure is supported by a transparent substrate on which the apertured electrode has been deposited. The electrical conduction path of the photoconductor extends from approximately the edge of the aperture of said apertured electrode to the further electrode, and its conductive properties are variable as a function of optical energy admitted through the aperture.

When fabricated in array form, the apertured electrodes of the photoconductor structure are common and made from a continuous strip of conductive material. The further electrodes are individually arranged and separated one from another by an insulating layer which insulates the photoconductor material from external connection at areas between the further electrodes and which may also serve to limit the area of the further electrodes in contact with the photoconductor.

When embodied in an electroluminescent-photoconductor image converter or amplifier device, the photoconductor structure is fabricated in array form and is overlayed by an electroluminescent layer, the external surface of which is coated with a transparent electrode.

BRIEF DESCRIPTION OF THE DRAWING

The specification concludes with claims particularly pointing our and distinctly claiming the subject matter which is regarded as the invention. It is believed, however, that both as to its organization and method of operation, together with further objects and advantages thereof, the invention may be best understood from the following description of the preferred embodiments taken in connection with the accompanying drawings in which:

FIGURE 1 is a plan view, partially broken away, of a photoconductor structure in accordance with the invention;

FIGURE 2 is a cross sectional view taken through the plane 2—2 in FIGURE 1;

FIGURE 3 is a plan view, partially broken away, of an electroluminescent-photoconductor image converter or amplifying device employing a photoconductor structure similar to that shown in FIGURES 1 and 2;

FIGURE 4 is a cross sectional view taken through the plane 4—4 in FIGURE 3;

FIGURE 5 is an electrical equivalent circuit for the structure of FIGURES 3 and 4; and

FIGURE 6 is a graph of the light output versus the photoconductor resistance of the electroluminescent-photoconductor device of FIGURES 3 and 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With refreence to FIGURE 1, there is illustrated a partially broken away plan view of a photoconductor structure **1** in accordance with the invention, which shows the various layers of the structure. The structure **1** includes a common electrode **2** having apertures **3** provided therein and individual electrodes **4** concentrically arranged with respect to the apertures **3**, the electrodes **4** having smaller dimensions than said apertures. A photoconductor material **5** extends between the common electrode **2** and the individual electrodes **4**, filling the apertures **3**. An insulating layer **6** having holes formed therein electrically insulates the photoconductive material from external connection at areas between the individual electrodes, as well as limits the effective area of the electrodes in contact with the photoconductor **5**.

As more clearly shown in the cross sectional view of FIGURE 2 taken along the plane **2—2** in FIGURE 1, the entire structure is mounted upon a glass substrate **7**. For purposes of clarity, the view of FIGURE 2 is not to scale. The common electrode **2** and the individual electrodes **4** are in different planes, effectively offset from each other so as to reduce the capacitance between them. The electrodes **4** are typically in the form of indium pellets. A reflective metal film **8**, such as gold or aluminum, deposited on the surface of the photoconductor **5** insures good electrical contact between the photoconductive material and the individual conductor pellets **4**. Conductor leads **9** and **10** are connected to the common electrode **2** and individual electrodes **4**, respectively.

Light energy is applied to the photoconductor structure from the underside of the glass substrate **7**, entering the apertures **3** and varying the resistivity of that portion of the photoconductor material which fills the apertures. The thin conductive coating **8** acts to reflect light incident thereat back through the photoconductor materials. At each photoconductor cite, current conduction extends primarily between the circular rim of the common electrode and the conductive coating through the bulk of the photoconductor material, there existing radially extending shunt conduction paths between the common and individual electrodes. By means of the illustrated concentric structure, the folding ratio, i.e., the ratio of the effective width to length of the aggregate conduction paths, is increased. Therefore, the resistance of each photoconductor element is reduced from that of a conventional structure of comparable dimensions. In addition, a high degree of input light energy is provided per unit area.

The photoconductor structure **1** is fabricated using processes that are standard in the art. Typically, the common electrode **2** is a platinum material that is applied to the glass substrate **7**, having a thickness of about 10 mils, by means of a reverse photoresist method wherein a photoresist material such as KPR is deposited upon the surface of the glass substrate in those areas where the apertures **3** are to be formed. The platinum is sputtered over the entire surface of the glass to a thickness of approximately 2000–5000 angstroms. When placed in solution, the photoresist material dissolves carrying away with its the overlaying platinum. The remaining platinum material is undisturbed and the common electrode layer **2** is thereby formed with the apertures **3**, these being approximately 40 mils in diameter in one operable embodiment of the invention. In the next step of the process, a photoconductive material such as CdSe or CdS is mixed in a sintered powdered form in an alcohol slurry, sprayed over the common electrode layer to a thickness of about 1–2 mils and fired so as to achieve the desired photoconductive properties and to adhere at the undersurface. A metallic film of gold or aluminum is then evaporated onto the surface of the photoconductor through a mask, not shown, so as to form the coatings **8** within the area of the apertures **3**. The conductive coatings each have a diameter of about 20 mils in the operable embodiment being considered, with the minimum conduction path therefore slightly more than 10 mils. The relative dimensions between the individual electrodes and the apertures may be somewhat different from that indicated. Thus, by reducing the spacing between electrodes so as to reduce the mean conduction path length, the photoconductor resistance can be decreased, the limit being the dimension at which voltage breakdown occurs through the photoconductor material. Conversely, the photoconductor resistance is increased by increasing the electrode spacing.

The insulating member **6**, which is a plastic layer such as mylar having holes therein of the same dimension as the conductive coatings **8**, is next laid over the structure thus far formed. The member **6** has a thickness of approximately 7–8 mils in the operable embodiment being considered. The holes in the member **6** are then filled with individual indium pellets, a material of relatively low melting point permitting it to flow at a temperature that will not adversely affect electroluminescent material. The entire structure is then laminated together under the application of heat to about 170° C. and pressure to about 20 p.s.i.

In FIGURES 3 and 4 there is illustrated an electroluminescent-photoconductor device **20** providing image conversion or amplification, which structure employs the basic photoconductor structure **1** of FIGURES 1 and 2. FIGURE 3 is a partially broken away plan view and FIGURE 4 is a cross sectional view of FIGURE 3 taken along the plane **4—4**. Elements that are repeated in FIGURES 3 and 4 are identified with the same reference characters as previously, but with an added prime notation. Thus, the device **20** is seen to be different from that hereinbefore considered only in the addition of an electroluminescent layer **21** and a slightly modified configuration of the individual electrodes **4'**. The individual electrodes **4'** and the insulating layer **6'** are opaque to light energy emitted by the electroluminescent cell. The individual electrodes provide discrete connections of the photoconductor elements to the electroluminescent film so as to control the voltage across elemental portions of the electroluminescent layer and thus the light emission therefrom.

The electroluminescent layer **21** includes an electroluminescent material **22** and a transparent common electrode **23** deposited thereon. A standard electroluminescent material that may be employed, includes a zinc sulphide phosphor embedded in a plastic binder, such as manufactured by General Electric Company. A pair of conducting leads **24** and **25** are connected to the transparent electrode **23** and the common electrode **2'**, respectively. An A-C source voltage **26** is provided for energizing the electroluminescent-photoconductor structure.

In response to an optical image applied from the underside of the device **20** to the photoconductor material, the elemental resistivity of the individual photoconductor elements will vary as a function of the light energy intensity so as to cause an according variation of voltage across corresponding portions of the electroluminescent layer **21**. Optical feedback is prevented from occurring between the electroluminescent and the photoconductor elements by means of the opaque insulating layer **6'** and the electrode pellets **4'**.

An electrical equivalent circuit for the electroluminescent-photoconductor device of FIGURES 3 and 4 is shown in FIGURE 5. The structure includes a plurality of electroluminescent-photoconductor shunt paths each including a photoconductor element **30** in series with an electroluminescent element **31**. The shunt paths are connected between the photoconductor common electrode and the electroluminescent common electrode, and across the A-C voltage source **26'**.

It is necessary for a proper operation of the device, i.e., one in which the electroluminescent elements' light output ranges from fully ON to fully OFF that the following relationships exist:

$$R_{pc}\ (\text{light}) \ll |Z_{EL}| \ll R_{pc}\ (\text{dark}) \qquad (1)$$

where R_{pc} (light) is the resistance of the photoconductor when exposed to bright light, R_{pc} (dark) is the resistance of the photoconductor unexposed and $|Z_{EL}|$ is the elemental impedance magnitude of the electroluminescent layer, and

$$Xc_{pc} \gg R_{pc}\ (\text{dark}) \qquad (2)$$

where Xc_{pc} is the capacitive reactance of the photoconductor.

Referring to the relationships (1) and (2) above, it is necessary that the light resistance of each photoconductor be appreciably smaller than the impedance of the associated electroluminescent element so that for an exposed photoconductor the source voltage is primarily across the electroluminescent element, causing it to brightly emit light. On the other hand, the dark resistance of the photoconductor should be considerably greater than the impedance of the electroluminescent element so that very little voltage is across it and no light emission will occur. In addition, it is a requirement that the capactive reactance of the photoconductor be large in order that the photoconductor support sufficient voltage in the dark condition for extinguishing the electroluminescent element, and so that the impedance of the photoconductor is widely variable as a function of its light sensitive resistance. These criteria are very well satisfied by the present structure wherein the concentric arrangement of the electrodes obtains good optical efficiency and a very low photoconductor resistance when exposed, and the capacitance between the common and individual electrodes is extremely low relative to that of the electroluminescent elements.

In one operable embodiment of the electroluminescent-photoconductor device **20**, a panel of 400 pairs of elements was constructed, 20 on a side. The capacitance of each photoconductor element was found to be 1.25×10^{-14} farads. As compared to the capacitance of the corresponding electroluminescent element, this yielded a ratio between capacitances C_{EL}/C_{PC} of 800. For 125 volts RMS and 400 c.p.s. applied across the electroluminescent-photoconductor structure, a light output in percent vs. photoconductor resistance characteristic was obtained, as shown by the curve in FIGURE 6. Primarily as a result of providing a large capacitance ratio C_{EL}/C_{PC}, such as indicated, the photoconductor resistance is seen to be effective in controlling light output of the electroluminescent layer from 100% output down to essentially zero emission. By contrast, with a relatively large photoconductor capacitance, for example on the order of that of the electroluminescent element, the light output cannot be reduced to less than about 30% emission no matter how high the photoconductor resistance becomes, due to the limiting capacitive reactance of the photoconductor.

The appended claims are intended to include within their ambit all changes and modifications to the structure that has been specifically disclosed herein that reasonably fall within the true scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A photoconductor structure comprising:
   (a) an apertured electrode formed on a planar surface,
   (b) photoconductive material overlaying said apertured electrode having a resistance that is a function of optical energy intensity admitted to the aperture of said apertured electrode, and
   (c) a further electrode having dimensions smaller than said aperture overlaying said photoconductive material and concentrically arranged with respect to said aperture.

2. A photoconductor structure as in claim **1** that is in array form wherein said apertured electrode is a continuous layer of conductive material in which a plurality of apertures have been formed, said layer deposited on a transparent dielectric substrate, there being a plurality of further electrodes overlaying the photoconductive material, one for each aperture.

3. A photoconductor structure as in claim **2** which includes a continuous layer of insulating material in which a plurality of holes have been formed overlaying said photoconductive material, said further electrodes being located within said holes.

4. A phototconductor structure as in claim **3** wherein said further electrodes each include a metallic film deposited on the surface of the photoconductive material and a metallic pellet bonded to said film.

5. An electroluminescent-photoconductor device comprising:
   (a) an apertured electrode formed on a first planar surface,
   (b) a photoconductive material overlaying said apertured electrode having a resistance that is a function of the optical energy intensity admitted to the aperture of said apertured electrode,
   (c) a further electrode having dimensions smaller than said aperture overlaying said photoconductive material and concentrically arranged with respect to said aperture, and
   (d) an electroluminescent material in contact with said further electrode, said electroluminescent material having a transparent external electrode, whereby in response to the application of electrical energy be-

tween said apertured electrode and transparent electrodes light is emitted by said electroluminescent material with an intensity that is a function of the photoconductor resistance.

6. An electroluminescent-photoconductor device as in claim 5 that is in array form wherein said apertured electrode is a continuous layer of conductive material in which a plurality of apertures have been formed, said layer deposited on a transparent dielectric substrate, there being a plurality of further electrodes overlaying said photoconductive material, one for each aperture.

7. An electroluminescent-photoconductor device as in claim 6 which includes a continuous layer of insulating material in which a plurality of holes have been formed overlaying said photoconductive material, said further electrodes being located within said holes.

8. An electroluminescent-photoconductor device as in claim 7 which includes a metallic film deposited on the surface of the photoconductive material and a metallic pellet bonded to said film.

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ARCHIE R. BORCHELT, Primary Examiner

T. N. GRIGSBY, Assistant Examiner

U.S. Cl. X.R.

250—211, 220; 313—108; 338—15, 17