United States Patent

Kohashi

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[54] AN ENERGY RESPONSIVE IMAGE CONVERSION AND AMPLIFICATION DEVICE

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.**.....**315/169,** 250/213, 313/108

[51] **Int. Cl.**.....**H05b 33/02,** H05b 37/00

[58] **Field of Search**.....313/108; 250/213; 315/169

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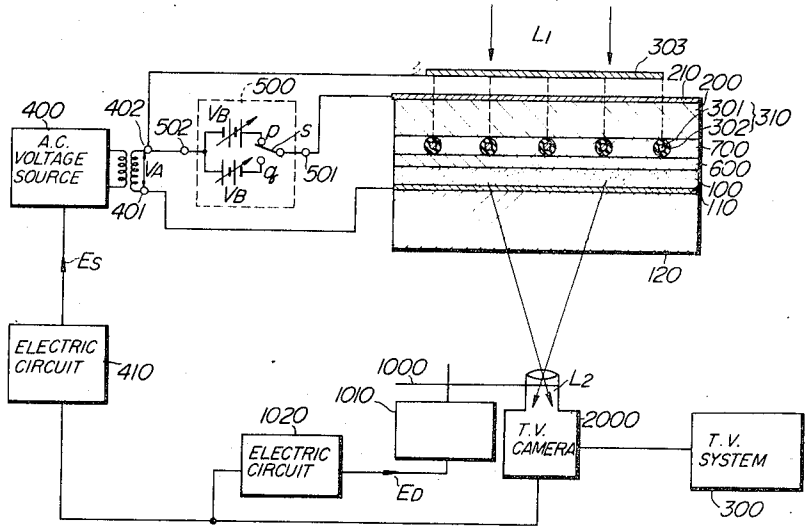
[57] **ABSTRACT**

A solid-state electroluminescent image display device which produces the output thereof in response to an image of the light, X-ray or other types of energy projected on to said device, said output being able to be controlled by varying a DC bias voltage for said device, and which comprises an electroluminescent layer excited by an AC electric field and controllable by a DC field and an energy-responsive layer whose resistivity varies in response to the incident energy such as a photoconductive layer, said two layers being interposed between a first light-pervious electrode and a second electrode in such a manner that the electroduminescent layer is adjacent to said first electrode, a third or composite electrode place between said two layers, the AC exciting voltage being connected between said first and third electrodes and the DC bias voltage between said second and third electrodes.

9 Claims, 2 Drawing Figures



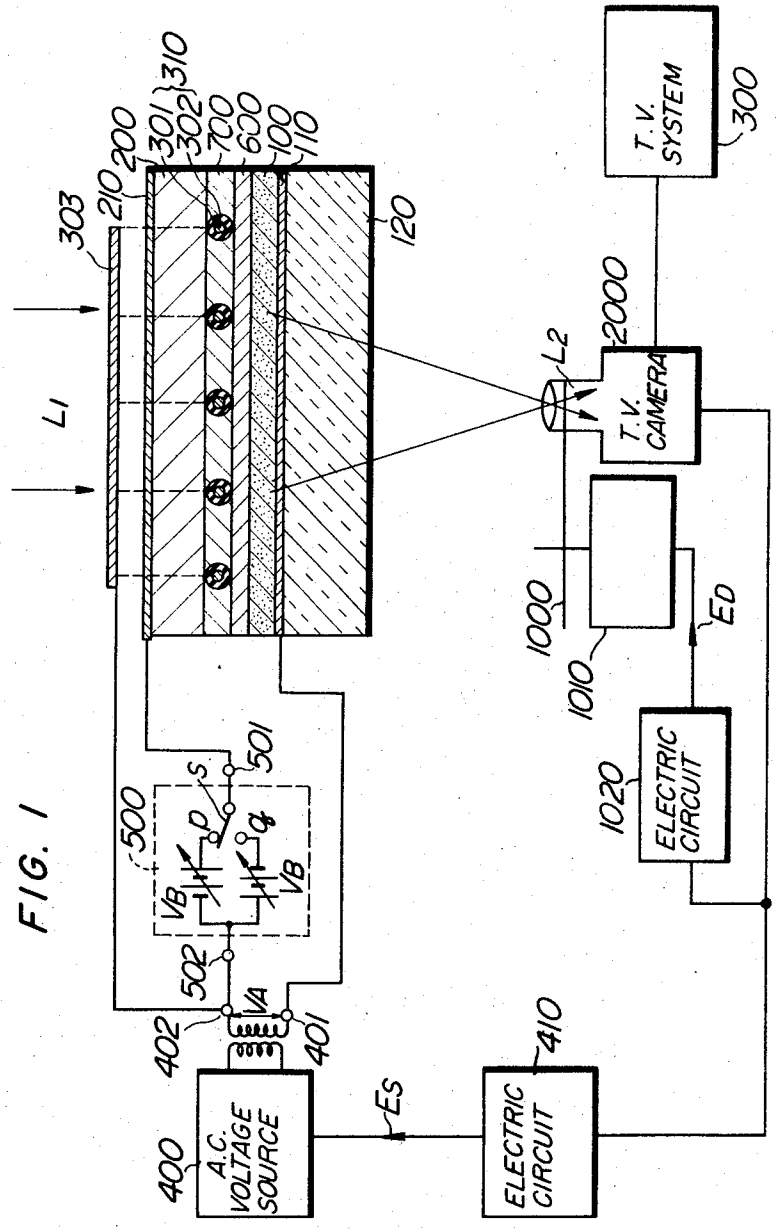


FIG. 1

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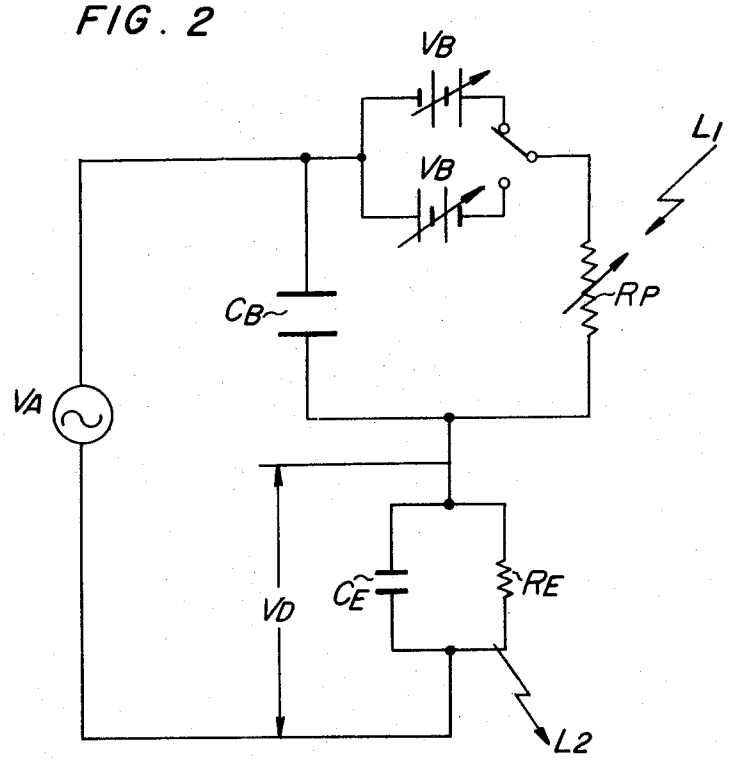
FIG. 2



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AN ENERGY RESPONSIVE IMAGE CONVERSION AND AMPLIFICATION DEVICE

This invention relates to an energy-responsive image conversion and amplification device in which an electroluminescent element is energized to luminescence with an alternating electric field and at the same time, the luminescent output of said element being affected by a DC voltage whose magnitude depends on variation in the impedance of an energy-responsive element in relation to incident energy, thus the electroluminescent output from said element being controlled with relation to the incident energy.

More particularly, this invention relates to an image plate for visualizing and amplifying an image of such energy as light, x-rays or gamma rays or further for storing and displaying such an image, on the ground of the above-described principle which is described in detail in the U.S. Pat. No. 3,525,014 granted to the present applicant on Aug. 18, 1970.

In conventional energy-responsive luminescent devices, control of the luminescence has been achieved, in principle, by controlling the alternating current supplied to the electroluminescent element, said alternating current in turn being controlled according to the AC component of a variation in the impedance of a photoconductive element. In such a device, however, the sensitivity of the photoconductive element under AC energization has been too low to be sufficiently useful. According to this invention, a DC control voltage is superimposed on the AC voltage in an ingenious manner so as to permit an expedient DC control. Thus, a remarkably improved energy-responsive luminescent device which has satisfactory characteristics of image conversion and amplification and which also allows for an image to be memorized therein, is obtained.

This invention will be explained hereunder in connection with an embodiment thereof and referring to the attached drawings in which;

FIG. 1 is a schematically shown sectional view of the embodiment of this invention shown with associated electric connection; and

FIG. 2 is a simplified electric circuit diagram equivalent to the arrangement shown in FIG. 1.

Now, referring to FIG. 1, a layer of AC–DC EL element **100** (this term will be explained in the next paragraph) is provided on one surface of a first light-pervious electrode **110**, and a layer of energy-responsive element, for example, consisting of a photoconductive element **200**, whose resistivity varies in connection with the excitation by an incident energy, is positioned in the opposite side of said AC–DC EL element **100** in relation to said first electrode **110** in contact with a second electrode **210** which is pervious to the incident energy. A divided or foraminate composite electrode **310** consisting of electroconductive members **301** coated with dielectric material **302** of a high resistivity is interposed between said first and second electrodes.

In this specification, the term "AC–DC EL element" defines an electroluminescent (hereafter referred to as EL) element which comprises, for example, EL material dispersed in dielectric medium of resistive type or of accumulatively polarizable type which supports the internal electric field when an external polarizing unidirectional voltage is applied thereto and maintains the residual component of said electric field when said external voltage has been removed therefrom, the waveform of the luminescent output from said element due to the excitation with an AC electric field being controllable by a DC electric field applied thereto.

More tangible features of the construction and the manufacturing method of this device will be explained hereunder. Reference numeral **120** indicates a support plate of transparent and heat-resistive material such as glass, which is coated with said first electrode **110** which consists of a heat-resistive and light pervious metal oxide such as tin oxide. To this first electrode **110** applied and fused is a layer of the AC–DC EL material in thickness of the order of 20 to 50 microns, said AC–DC EL material comprising powdered dielectric medium of electro-resistive or accumulatively

polarizable type such as glass enamel containing electro-resistive (i.e., slightly conductive) metal oxide such as SnO_2 and further containing Li or Li and Ti, and mixed with powdered EL fluorescent material such as ZnS. Then, an electro-resistive (i.e., slightly conductive) layer of an intermediate element **600** is applied onto said AC–DC EL layer. Said element **600** is made from a mixture of, for example, epoxy resin and powdered electro-resistive material such as pulverized carbon or SnO_2, or a mixture of powdered frit, an inorganic black pigment and powder of electro-resistive material such as SnO_2, said mixture being bonded by heating to become an electro-resistive and non-pervious layer. Addition of ferro-electric material such as $BaTiO_3$ to said mixture will be effective for reducing the AC impedance of the resultant layer. Said intermediate layer **600** prevents the luminescent output of the EL element **100** from being fed back to the photoconductive element. However, in case some degree of feedback is desirable, the intermediate layer **600** is made semi-pervious accordingly. Further said layer **600** can be formed as a composite layer, the additional elements being interposed between the non-pervious layer and the AC–DC EL element **100**. For example, an additional layer is made from a mixture of powder of frit or epoxy resin and powder of a ferro-electric and light-reflective material (most preferably $BaTiO_3$) or an electro-resistive metal oxide such as SnO_2, said mixture being fused and bonded by heating to become an electro-resistive reflecting layer. Thickness of the intermediate layer **600**, single or composite, should be 5 to 10 microns for a non-pervious layer and 10 to 20 microns for a reflective layer so that the resistivity of the layer **600** across the thickness is appropriately low as compared with that of the EL element **100**. The intermediate element **600** may be endowed with an extremely non-linear resistivity in order to prevent the increase of DC current. This may be achieved by the use of a non-linear resistive material such as CdS:Cl or SiC instead of the resistive metal oxide in the above-described composition. At least one of either the resistive reflecting layer or the non-pervious layer can be eliminated in this case.

On the intermediate element **600**, or the AC–DC EL element **100** if the intermediate element **600** is omitted, is disposed a divided or foraminate composite electrode **310** which consists of conductors **301**, for example, of tungsten or copper wire of about 10 to 30 microns in diameter coated with a highly dielectric material **302** such as polyester resin or glass in thickness of, for example, 2 to 10 microns. In the present embodiment, the composite electrode **310** is formed in the shape of a grid with juxtaposed lines. A composite electrode **310** of another type may be formed either by reticulating the above-described coated conductors or by coating a metallic network with the above-mentioned dielectric material. The space factor of the conductor **301** in said composite electrode **310** should be such that said electrode **310**, in spite of its foraminate formation, produces a substantially similar effect with respect to the AC field as that with a solid plate electrode when an AC operating voltage V_A is applied between the first electrode **110** and this composite electrode **310**. In other words, the composite electrode **310** should be constituted in such a form that the exciting AC power for the AC–DC EL element **100** is not greatly affected by the variation in the resistivity of the photoconductive element **200**. The space between two adjacent lines in a grid type composite electrode **310** as shown in FIG. **1** should be preferably less than 400 microns. In a net (lattice) type electrode, it is desirable that the network is finer than 50 mesh. Such spaces in the composite electrodes provide passages for the DC current between the AC–DC EL element **100** and the photoconductive element **200**.

In order to ensure the similarity of the composite electrode **310** to a solid plate electrode in the effectiveness for an AC field, an auxiliary resistive layer **700** is provided in the same plane as the composite electrode **310** is disposed, filling at least a part of said spaces in the composite electrode **310**. The resistivity of said resistive layer **700** is chosen at an ap-

propriate value so that excessive dispersion of the DC current can be prevented. An experiment showed that an auxiliary resistive layer **700** having a surface resistivity of 10^6 to 10^9 ohms-cm gave a satisfactory result. Accordingly, it will be understood that if the surface resistivity of said AC–DC EL element **100** and said intermediate element **600** fulfils the above-mentioned condition, the auxiliary resistive layer **700** is not required. Thus, the composite electrode **310** can be disposed on the intermediate element **600** or the EL element **100** without the auxiliary resistive layer; or further, said electrode **310** can be partly or entirely sunk in said element **600** or **100**. In the latter case, the auxiliary resistive layer **700** can be assumed to be included in at least either one of the non-pervious layer or the reflective layer of said intermediate element **600** or in the AC–DC EL element.

If the intermediate layer **600** and the dielectric coating **302** are made of a vitreous material, the auxiliary layer **700** is made from powder of epoxy resin or frit mixed with a resistive metal oxide such as SnO_2, said mixture being fused and bonded by heating. While, if the intermediate layer **600** and the dielectric coating **302** are made of a binder of low melting point such as epoxy resin, a similar binder mixed with the resistive metal oxide is used. In this case, powder of a highly dielectric material, especially a ferro-electric material such as $BaTiO_3$ may be added to the mixture to reduce the AC impedance of the resultant layer. Thickness of the auxiliary layer **700** is set, for example, at about 10 to 50 microns to limit the resistivity across the thickness. Further, the auxiliary layer **700** may be endowed with a significantly non-linear resistivity in order to minimize the DC voltage loss across the thickness and the dispersion of the DC current in the direction of the plane. This feature of the layer **700** may be attained by the use of a non-linear resistive material such as CdS:Cl or SiC in lieu of the resistive metal oxide in the above-mentioned composition. Moreover, the auxiliary layer **700** may be endowed with functions of a non-pervious layer and a light-reflective layer by the use of the above-mentioned materials selected for the respective purposes. With the use of this type of auxiliary layer, the constitution of the device of this invention can be simplified.

Next, the energy-responsive element **200**, that is a photoconductive layer in this embodiment is formed from a mixture of a binder such as epoxy resin and a photoconductive material such as CdS, CdSe or CdS·Se, said mixture being applied in a layer and bonded by heating. In case the dielectric coating **302**, the auxiliary resistive layer **700** and the intermediate element **600** are made of a heat-resistive material such as vitreous material as described previously, the mixture applied on the lamination formed on the support plate **120** may be heated at 600° C. for about 5 minutes, for example, in vacuum or in inactive atmosphere of nitrogen, thereby to become a layer of sintered photoconductive element **200** containing CdS, CdSe or CdS·Se.

The sintered photoconductive element, having substantially linear characteristics of voltage versus photoelectric current, makes possible an operation with considerably high sensitivity in comparison with an unsintered element.

In a lamination in which the auxiliary layer **700** is omitted, the photoconductive element **200** is formed in a layer filling the vacant spaces in the composite electrode **310**. If the composite electrode **310** is completely sunken in the EL element **100** or the intermediate element **600**, the auxiliary layer **700** is formed over said element **100** or **600**. While, if said electrode **310** is not entirely sunken in said element **100** or **600**, said layer **700** is formed filling the vacant spaces in said electrode **310**.

The photoconductive element **200** decreases its resistivity in response to an incident energy such as the light or X-ray. Dark-resistivity of said element **200** should be higher than 10_9 ohms-cm, for example. Thickness of said element **200** should be chosen to be 50 to 500 microns so that the dark-resistivity in the direction of thickness of said element **200** is similar to or rather higher than the resistivity of the AC–DC EL element **100** in the direction of thickness.

Then, the second electrode **210** is applied over the photoconductive element **200**. The second electrode **210** is formed so as to be pervious of the incident energy including the light, X-ray and other radiative rays, and further to be electroconductive. For example, the second electrode **210** is made of foil of gold or aluminum, or vapor-deposited film of a metal, or silver paint. Further, the second electrode **210** may be made in the form of a grid comprising metallic wires of about 10 to 50 microns in diameter juxtaposed with a space of about 100 to 500 (If the composite electrode **310** has the form of a similar grid, the grid of the second electrode **210** should be positioned in such manner that the members of said grid cross those of said electrode **310**, or come between the latter members in the horizontal projection.) or in the form of a metallic network. The second electrode **210** of such a foraminate formation can be partly or completely sunken in the photoconductive element **200**. Further, a second foraminate electrode has an advantage in that the variation of the resistivity in the direction of the plane can be utilized.

The first electrode **110** is connected to one terminal **401** of an AC voltage source **400**, and the conductor **301** of the composite electrode **310** to the other terminal **402** of said source **400** through a feeder bar **303**, thus the AC operating voltage V_A being applied between said electrode **110** and **310**.

The second electrode **210** is connected to one terminal **501** of a DC bias voltage source **500**, while the other terminal **502** of said voltage source **500** is connected to said terminal **402** of said AC voltage source **400** thereby to supply a bias voltage V_B to the second electrode **210**. The DC voltage source **500** is arranged so that the DC bias voltage V_B is variable and the polarity of said voltage V_B can be changed to give the AC–DC EL element **100** different operating characteristics. Thus, depending on whether the switch s is in contact with the terminal *p* or *q* (refer to FIG. **1**), the electrode in the luminescent output side of the AC–DC EL element **100**, that is, the first electrode **110** is biased negatively or positively. In the former case, the device is operative mainly for conversion and amplification of an image of the energy as well as erasing of the undermentioned stored image; and in the latter case, mainly for writing of an image and the luminescent display of the stored image.

FIG. **2** is a simplified equivalent circuit of the arrangement described above in connection with FIG. **1**. For simplicity of the explanation, functions of the auxiliary resistive layer **700** and the intermediate element **600** are omitted in FIG. **2**. Marking R_P indicates resistance of the photoconductive element **200** across its thickness, said resistance being variable; C_B capacitance across the dielectric coating **302** of the composite electrode **310**, the conductor **301** being one electrode; and C_E and R_E respectively capacitance and resistance across the thickness of the AC–DC EL element **100**.

As is seen from FIG. **2**, the resistance R_P decreases in accordance with the intensity of the incident energy L_1 such as the light or X-ray, and consequently the DC bias voltage V_D distributed across the AC–DC EL element is increased. As a result of this increase in the bias voltage, the waveform of the AC luminescent output L_2 produced by AC power supplied through the capacitance C_B is controlled so that amplitude of said waveform is significantly reduced in particular half cycles of each one cycle of the AC power.

Therefore, with this embodiment, an image L_1 of the energy such as the light or X-ray incident to the photoconductive element is converted and amplified with a high sensitivity and a high amplifing factor to an image of the luminescent output of negative polarity. It should be noted that in the device of this invention, the DC bias voltage V_B is applied between the energy-responsive element represented by the variable resistance R_P and the capacitive element represented by the capacitance C_B. Accordingly, dielectric strength of the capacitance C_B on which a relatively low DC voltage corresponding to the DC bias voltage V_D is imposed, is not required to be very high. Further, adjustment of the source voltage V_B does not affect the AC power fed to the AC–DC EL element **100**.

The above-described luminescent device having the form of a solid image plate can be used as a pre-amplifier for a television camera equipped with a vidicon or one of other image pickup tubes. The high sensitivity and the high energy amplifying factor of the luminescent device of this invention allow the conversion and amplification of an image of considerably low level or the pickup of an image means for sorting, i.e., selecting and separating the luminescent pulses by means of a light-chopper **1000** and a synchronous motor **1010** for driving said chopper **1000** are provided. In this means, the opening interval of said light-chopper **1000** should be shorter than at most one cycle period of the operating AC voltage V_A and preferably a half cycle period or shorter, said interval being adjustable. Frequency of the sorting operation is set at the same number as that of the operating AC voltage V_A.

As shown in the lower part of FIG. 1, the luminescent output image of controlled waveform radiated from the EL element **100** in response to the incident image L_1 is sorted in regard to particular luminescent pulse stored therein. Further, according to this invention, polarity of the obtained video signal is reversed to display a visible image of the positive polarity relating to the incident image of the energy, on the screen of the television system **300**. Such a device utilizing the closed television system is very useful as an X-ray television system for the industrial use or the medical use.

If means for adjusting or controlling the image reproduction characteristics such as contrast is provided in the television system, the under-described means for sorting the luminescent pulses is not necessarily needed.

In order to improve the reproduced image, by means of the light-chopper **1000** provided in the optical system of the television camera **2000**, the photoelectric screen of an image tube in the television camera **2000** is excited by the output image of the thus sorted luminescent pulse L_2.

In a system wherein a television camera is used, the ratio of the frame frequency of the image tube against the sorting frequency for the luminescent pulses or the frequency of the operating AC voltage V_A should be a round number to avoid the beat or the flicker in the television picture, usually the latter frequency being set at a higher number than the former. In order to maintain such a synchronized relation between these two frequencies, the sweep signal or synchronizing signal of the horizontal or vertical scanning of the television system is used as the input signal E_S of the AC voltage source **400** and the timing or synchronizing signal for the driving signal E_D of the synchronous motor **1010**. That is, said signals E_S and E_D are produced from said timing signal in the respective electric circuits **410** and **1020** so that the ratio of the frequency of said signals E_S and E_D against that of said timing signal becomes a round number and further the phasic relation between the formers and the latter is adjustable. With this arrangement, adjustability of the operating characteristics can be attained.

In the aforegoing embodiment of this invention, the composite electrode **310** is positioned between the AC–DC EL element **100** and the energy-responsive element or the photoconductive element **200**. In this arrangement, the total thickness of the layers including the intermediate element **600**, the auxiliary resistive element **700** and any other additional elements, if desired, may be made the same as thickness of the composite electrode or lesser than that so that the whole of said elements can be put in the vacant space of the composite electrode **310**. Such a constitution is advantageous in the point that dispersion of the DC current is prevented.

The composite electrode **310** can be partly embedded into at least either one of the DC–AC EL element **100** or the energy-responsive element **200**.

Further, relative thickness of the composite electrode **310** is not limited by thickness of the EL element **100** and the photoconductive element **200**, but only have to be lesser than the distance between the first electrode **110** and the second electrode **210**. As to the position of the composite electrode **310**, it is only required to be between the first electrode **110** and the second electrode **210** without any other limitation. Therefore, at least either one of the EL element **100** or the photoconductive element **200** can be contained within the vacant space of the composite electrode **310**.

In the above-described embodiment of this invention, a photoconductive element is used as the energy-responsive element. However, in a device according to the principle of this invention, the energy-responsive element is only required to vary its resistance in response to an excitation by any type of incident energy. Therefore, an energy-responsive element other than the photoconductive element such as a stress sensitive resistance element or a magneto-resistance element can be utilized, the resistivity thereof being controlled by elastic energy or magnetic energy respectively.

What we claim is:

1. An energy-responsive image conversion and amplification device comprising a first electrode which is planar and light-pervious; an electroluminescent layer provided on said first electrode, which can be excited by an AC electric field and waveform of whose luminescent output is changeable by a unidirectional electric field thereacross; a second electrode provided on the opposite side of said electroluminescent layer in regard to said first electrode; an energy responsive layer which varies the resistivity thereof in response to an energy applied thereto and which is provided between said second electrode and said electroluminescent layer; a grid- or net-shaped third electrode consisting of conductors coated with dielectric material, said third electrode being positioned between said electroluminescent layer and said energy responsive layer; means for applying an AC voltage between said first and third electrodes to cause said electroluminescent layer to luminesce; and means for applying a DC voltage between said second electrode and said first electrode to change the waveform of the AC excited luminescent output according to the variation in the resistance of said energy responsive layer.

2. A device as defined in claim **1**, wherein a resistive intermediate layer is provided between said electroluminescent layer and said energy-responsive layer.

3. A device as defined in claim **2**, wherein said intermediate layer contains ferro-electric material.

4. A device as defined in claim **2**, wherein said third electrode is disposed adjacent the interface between said intermediate layer and said energy responsive layer.

5. A device as defined in claim **2**, wherein said third electrode is disposed across the interface between said energy responsive layer and said intermediate layer.

6. A device as defined in claim **2**, wherein said third electrode is embedded within said intermediate layer.

7. A device as defined in claim **1**, wherein the thickness-wise resistance of said electroluminescent layer is lower than the maximum value of the thickness-wise resistance of said energy responsive layer.

8. A device as defined in claim **2**, wherein the maximum value of the thickness-wise resistance of said energy responsive layer is higher than the total value of the thickness-wise resistances of the remaining layers.

9. A device as defined in claim **1**, wherein said means for applying a DC voltage includes means for changing the polarity and magnitude of the voltage.

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