

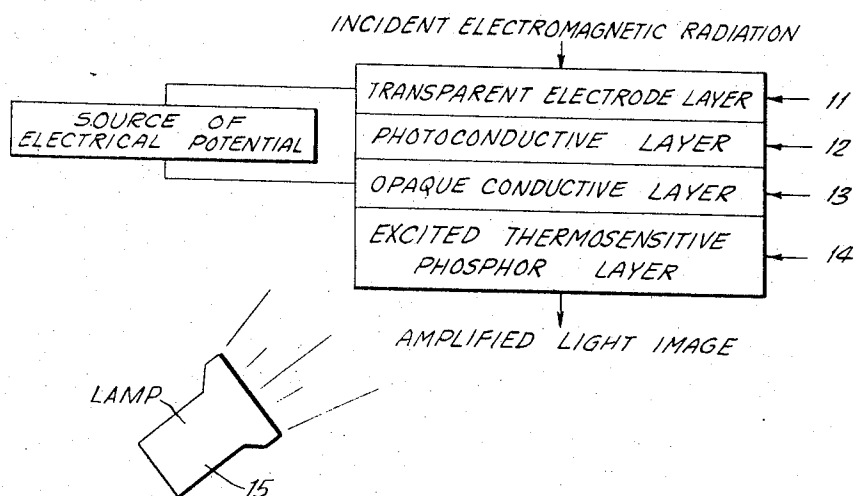
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THERMALLY COUPLED IMAGE AMPLIFIER

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THERMALLY COUPLED IMAGE AMPLIFIER

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16 Claims

ABSTRACT OF THE DISCLOSURE

A method and device in which a photoconductor is used to convert an electromagnetic-radiation image (e.g., in the visible or near-visible spectrum) to patterns of electric current, the heat generated by the current pattern thereafter being used to quench or stimulate the fluorescence of an externally-excited phosphor to reform the original image in fluorescent light.

This invention relates to improvements in image amplifiers and more particularly to image amplifiers employing thermosensitive phosphors the stimulated light emission of which is either quenched or intensified by the application of heat.

Many systems are known in the art which produce image amplification and conversion. One such system utilizes a sandwich comprising, sequentially, a transparent electrode layer, a photoconductive layer, an opaque electrically conducting layer, an electroluminescent layer and a second transparent electrode layer, said electrodes being connected to a source of electrical potential. It should be noted here that it is a characteristic of photoconductive materials that their electrical resistance decreases with exposure to electromagnetic radiation thus permitting increased current flow, the magnitude of said current being directly proportional to the intensity of the incident radiation. It should also be noted that it is a characteristic of electroluminescent materials that their luminescence increases with increases in the density of electrical current flowing through them. It follows, therefore, that when a radiation image impinges upon the surface of the photoconductive layer of the image amplifier being described, with a voltage applied across the transparent electrodes, current flows through the irradiated portions of the photoconductive layer and through the electroluminescent layer to produce a replica of the original radiation image in the electroluminescent layer.

Another system of image amplification known in the art utilizes the heat produced by the flow of electrical current through a photoconductive layer and an excited thermosensitive phosphor layer to modulate the light emission or fluorescence of the excited thermosensitive phosphor layer. The light emission of the phosphor layer may increase or decrease with increases in temperature depending upon the composition of the particular phosphor employed in the layer. This system of light amplification employs a sandwich comprising, sequentially, a transparent electrode layer, a photoconductive layer, a thermosensitive phosphor layer and a second transparent electrode layer, said electrode layers being connected to a source of electrical potential and the phosphor layer being excited by an externally applied source of stimulating radiation, e.g., an ultraviolet lamp. When an electromagnetic radiation image impinges upon the surface of the photoconductive layer of such a system, current flows through the irradiated portions of the photoconductive layer and through the phosphor layer to produce a heat pattern in the phosphor layer of a magnitude and distribution dependent upon the intensity and distribution of the incident radiation and the product of the electrical resistance and the square of

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the current flowing through the photoconductor and phosphor layers. This heat pattern produces a light pattern in the phosphor layer which may be either a negative or a positive replica of the original radiation image depending upon whether the fluorescence of the phosphor layer is quenched or stimulated by the local increases in temperature produced by the heat pattern.

A close examination of the image amplifier employing a thermosensitive phosphor layer described above reveals that it suffers an inherent disadvantage in that the arrangement of the layers of the image amplifier require that the current which produces the amplified or converted radiation image flow through both the photoconductive layer and the excited phosphor layer. This arrangement seriously impairs the efficiency of the system since the phosphor layer has a relatively high electrical resistance which impedes the flow of current through the system thereby reducing the amount of heat generated in the phosphor layer by the photocurrent flowing through the system. Another disadvantage which is inherent in this image amplifier, as it is described in the prior art, is that the high thermal capacity of the system dissipates heat which is required by the thermosensitive phosphor layer to obtain any reasonable degree of efficiency. These disadvantages may be obviated and the efficiency of the image amplifier greatly increased by an arrangement which affords a system having low thermal capacity and which does not require that the heating current flow through the thermosensitive phosphor.

According to a preferred embodiment of the present invention, a photoconductive layer sandwiched between a transparent electrode and a thin heat conductive electrode is exposed to an image of electromagnetic radiation to produce an electrical conductivity pattern through which electrical current is passed to produce a current pattern. This current pattern produces a thermal image corresponding to the current pattern. On the other side of the thin electrode is a thermosensitive phosphor layer which responds to the thermal image transmitted through the thin electrode. The thermosensitive phosphor may be one which fluoresces under actinic radiation and is quenched by the thermal image to produce a negative replica of the applied image or it may be one which is pre-excited by actinic radiation and is stimulated by the thermal image to produce a positive replica of the applied image. The simpler form of the present invention utilizes the former type phosphor which is continuously illuminated by ultraviolet light and gives a negative image due to the quenching. It is surprising that high definition and good resolution are obtained when the heat is created on one side of the thin electrode and reaches the thermosensitive phosphor through the electrode. Nevertheless, fine results are obtained.

The front electrode must be transparent to the electromagnetic radiation which causes the electrical current pattern. This radiation may be visible light, infrared, ultraviolet, X-rays or any radiation to which the variable conductivity layer is sensitive. The rear electrode is preferably opaque since its function is merely to conduct electricity and heat. Heat transfer is by conduction, not by radiation.

As noted above, previous attempts to use a thermoluminescent or thermally quenched phosphor in a photoconductive sandwich specifically between the photoconductor and the rear electrode have encountered many difficulties. In the first place, if the image is to be seen from the rear, the rear electrode as well as the front one must be transparent. This introduces additional resistance which cuts down on the current, which in turn cuts down on the amount of heating. For the thermoresponsive phosphor to be highly sensitive, it too must have high

electrical resistance. With the present invention on the other hand, it is quite surprising that there is no appreciable loss of definition when the thermoresponsive phosphor is put on the outside of the sandwich and, of course, the effect is much greater because of the lower resistance and hence higher temperature of the heat image. For the purposes of the present invention it does not matter how the original radiant energy image is converted to a conductivity image. The invention merely requires current to be passed through the conductivity image to a thin electrode on the other side of which there is a thermoresponsive phosphor through which no current flows at any time.

It is thus an object of this invention to provide an improved image amplifier which is highly efficient and which produces substantial image amplification.

It is a further object of this invention to provide an improved image amplification system which is capable of giving either negative or positive images with respect to the applied image.

It is still another object of the present invention to provide an improved image amplifier which can operate at very high output intensity levels.

These and other objects, which will be evident from the following description and drawing, are accomplished by reducing the thermal capacity of the system and by providing an arrangement wherein the heating current does not have to pass through the thermosensitive phosphor layer.

The accompanying drawing is a schematic view of the layer arrangement of a preferred embodiment of the image amplifier of the present invention.

Referring to the accompanying drawing, layer 11 comprises a transparent electrode, layer 12 comprises a photoconductive layer, layer 13 comprises an opaque layer having a high degree of heat and electrical conductivity and layer 14 is an excited thermosensitive phosphor layer which may optionally be covered with a protective transparent layer. For optimum efficiency of the system it is imperative that the sandwich comprising the layers 11 through 14 be made to have as low a thermal capacity as is consistent with the optimum efficiency of the individual layers.

In the operation of the image amplifier of the present invention an electrical potential is applied between electrodes 11 and 13 and the phosphor layer 14 is excited by an external source of actinic radiation 15. When an image comprising a pattern of electromagnetic radiation is cast upon the photoconductive layer 12, locally decreasing its electrical resistance, current flows through the irradiated portions of the layer generating a heat pattern in the layer in accordance with the energy equation

$$P=I^2R$$

where P is representative of the heat produced, I represents electrical current and R represents the electrical resistance of the layer 12. (With alternating current applied to the system the same relation applies since the impedance of the system is almost completely resistive.) The heat pattern generated in the exposed areas of the photoconductive layer is then transmitted through the thin opaque conductive layer 13, which has little lateral thermal conductivity due to the temperature gradients of the system, to the excited thermosensitive phosphor layer 14 to either quench its fluorescence or intensify it depending upon the characteristics of the phosphor employed. Thus, either a negative or a positive amplified replica of the original image may be produced in accordance with the type of thermosensitive phosphor employed; a phosphor the fluorescence of which is quenched on heating affording a negative replica of the original image and a phosphor the fluorescence of which is stimulated by heat affording a positive replica of the original image.

In a preferred embodiment of the present invention, a layer of photoconductive cadmium sulfide in an epoxy resin was coated at a thickness of about 0.01 inch on Nesa (stannic oxide) glass and overcoated with a thin layer of conductive silver paste, the Nesa glass and the silver paste acting as electrodes. A thermosensitive phosphor coating comprising about 49% of zinc sulfide, 49% of cadmium sulfide, 2% of sodium chloride, 400 parts per million of silver and 2 parts per million of nickel in a non-fluorescent binder was then applied over the silver paste. The phosphor layer of the resulting sandwich was then irradiated with ultraviolet light to produce a uniform glow of fluorescent light which was reduced slightly in intensity on the application of 160 volts across the silver paste and Nesa glass electrodes (due to the small amount of dark current flowing in the photoconductive layer). An image of white light having an intensity of 0.5 foot-candles at the image plane was then applied to the photoconductive cadmium sulfide layer through the Nesa glass electrode to produce in the thermosensitive phosphor layer an image which was negative with respect to the applied image, the fluorescence of the phosphor layer being quenched in the areas corresponding to the illuminated areas of the photoconductive layer. Since the brightness of the fluorescent image in the thermosensitive phosphor layer was significantly greater than the brightness of the image applied to the photoconductive layer, image amplification was accomplished.

While the preferred embodiment described above produced a negative replica of the applied image in the thermosensitive phosphor layer, it is equally possible to produce a positive replica of the applied image by using a thermosensitive phosphor in the image amplifier which stores excitation energy and subsequently releases it in the form of visible light when the temperature of the phosphor is increased.

As was mentioned above, it is imperative in the construction of the image amplifier that the sandwich (comprising layers 11 through 14 in the drawing) be made to have as low a thermal capacity as is consistent with the optimum efficiency of the individual layers if maximum sensitivity and efficiency are to be obtained. For example, the low thermal capacity transparent electrode layer could comprise a thin transparent conductive coating of evaporated metal on a transparent support having a low thermal capacity such as a thin film of polyethylene terephthalate. The photoconductive layer might be a thin layer of any suitable photoconductive material such as cadmium sulfide, zinc oxide, selenium, lead sulfide, antimony sulfide, lead selenide, arsenic selenide, etc. By proper choice of the photoconductive material employed, the image amplifier may be made responsive to electromagnetic radiations other than visible radiation, e.g., long X-rays, ultraviolet rays, near infrared rays, etc. It is to be noted that as used in the specification and claims, the term "amplify" and its derivatives such as "amplifying" and "amplification" are deemed to embrace not only amplification of an image of electromagnetic radiation but also the conversion of an image of one type of electromagnetic radiation to an image of another type of electromagnetic radiation. For example, according to the present invention, an incident image of visible radiation may be amplified to produce an image of visible radiation of greater intensity or an incident infrared image, ultraviolet image, etc. may be converted to an image of visible radiation, etc. It is equally obvious that with certain wavelengths of radiation not visible to the eye which produce heat on absorption in various materials, the photoconductive layer may be replaced by a layer which absorbs such radiation.

The thermosensitive phosphors useful in the practice of this invention may be selected from proprietary products such as those sold by the United States Radium Company or they may be prepared by methods known in the art. It is obvious that, by the proper selection of the thermosensitive phosphors, the color of the amplified image, the

brightness of the image, and the heat input energy requirements may all be varied to suit a particular application of the image amplifier.

Although specific embodiments of this invention have been described and illustrated above, it is obvious to those skilled in the art that other embodiments are possible which are within the scope of the present invention as described above and in the appended claims.

What is claimed is:

1. A method of amplifying electromagnetic radiation energy comprising the steps of casting an image of such radiation energy upon means for converting incident electromagnetic radiation energy into electrical conductivity, impressing an electrical potential across said electromagnetic radiation energy converting means in order to produce an electrical current pattern within such radiation converting means corresponding to the image of electromagnetic radiation cast thereon, said electrical current image producing a corresponding thermal image in said electromagnetic radiation converting means, and utilizing said thermal image to produce a light image in means for converting a thermal energy pattern into a light energy pattern, said thermal energy pattern converting means having no electrical current passing therethrough.

2. An electromagnetic radiation energy amplification device comprising a transparent electrode layer, an opaque heat-conductive electrode layer, a photoconductive layer intermediate said transparent electrode layer and one side of said opaque electrode layer, a thermosensitive phosphor layer in thermal contact with the other side of said opaque electrode layer, a source of electrical potential connected across said electrode layers, and an external source of actinic radiation to excite the thermosensitive phosphor layer.

3. The electromagnetic radiation energy amplification device of claim 2 wherein said transparent electrode layer comprises glass coated with stannic oxide.

4. The electromagnetic radiation energy amplification device of claim 2 wherein said photoconductive layer comprises cadmium sulfide.

5. The electromagnetic radiation energy amplification device of claim 2 wherein said opaque layer comprises a vacuum evaporated metal.

6. The electromagnetic radiation energy amplification device of claim 5 wherein said vacuum evaporated metal is gold.

7. The electromagnetic radiation energy amplification device of claim 2 wherein said thermosensitive phosphor layer comprises a phosphor the fluorescence of which is quenched by heat.

8. The electromagnetic radiation amplification device of claim 2 wherein said thermosensitive phosphor layer comprises a phosphor which stores energy which is released as light energy on heating.

9. An electromagnetic radiation energy amplification device comprising a sandwich having, in the following order, a transparent electrode layer as a first layer, a photoconductive layer as a second layer, an opaque heat conductive electrode layer as a third layer and a thermosensitive phosphor layer as a fourth layer, whereby when an electrical potential is impressed across said electrode layers and the thermosensitive phosphor layer is excited by an external source of actinic radiation, an image of electromagnetic radiation cast upon said photoconductive layer through said transparent electrode layer produces

an electrical current pattern in said photoconductive layer, the density of current at any point being a function of the intensity of the radiation cast upon said photoconductive layer at that point, said current pattern producing within said photoconductive layer a thermal image corresponding to said current pattern and said radiation image, said thermal image being transferred to said thermosensitive phosphor layer and causing a light energy pattern to be produced in said thermosensitive phosphor layer, the intensity of said emitted light being substantially greater than the intensity of the electromagnetic radiation image cast upon said photoconductive layer.

10. The electromagnetic radiation energy amplification device of claim 9 wherein said transparent electrode layer comprises glass coated with stannic oxide.

11. The electromagnetic radiation energy amplification device of claim 9 wherein said photoconductive layer comprises cadmium sulfide.

12. The electromagnetic radiation energy amplification device of claim 9 wherein said opaque layer comprises a vacuum evaporated metal.

13. The electromagnetic radiation energy amplification device of claim 12 wherein said vacuum evaporated metal is gold.

14. The electromagnetic radiation energy amplification device of claim 9 wherein said thermosensitive phosphor layer comprises a phosphor the fluorescence of which is quenched by heat.

15. The electromagnetic radiation energy amplification device of claim 9 wherein said thermosensitive phosphor layer comprises a phosphor which stores energy which is released as light energy on heating.

16. An electromagnetic radiation energy amplification device comprising, photoconductive means having electrical resistance which varies in accordance with incident electromagnetic radiation, thermosensitive means for producing a light pattern which varies in accordance with temperature, and circuit means for passing through said photoconductive means, but not through said thermosensitive means, electric current varying in accordance with the resistance of said photoconductive means, said thermosensitive means being positioned in thermally-responsive relation with said circuit means to produce light patterns corresponding to the heat patterns created by variations in said current.

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