

[54] LIGHT SENSING DEVICE

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[51] Int. Cl..... H03k 3/31, H03k 3/42, H03k 17/58

[58] Field of Search..... 307/322, 258, 311; 250/206

[56] References Cited

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Primary Examiner—James W. Lawrence

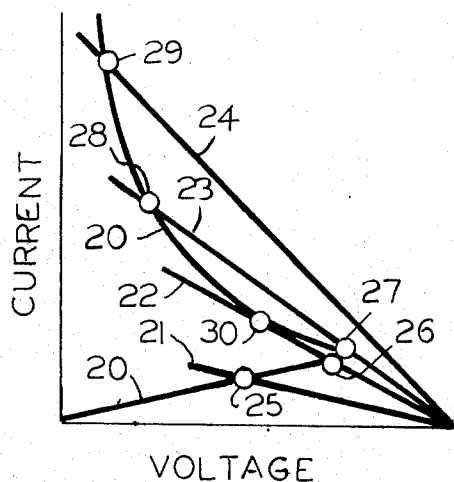
Assistant Examiner—T. N. Grigsby

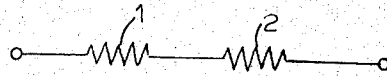
Attorney—E. F. Wenderoth et al.

[57] ABSTRACT

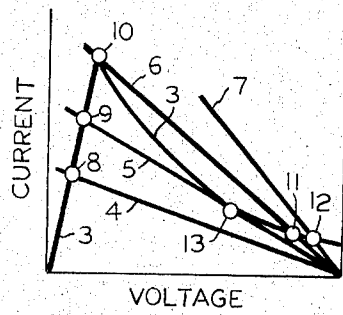
A light sensing device which can act as a light memory device or a light detecting device. The device has a photo-conductive element and a negative resistance element connected in series. At least one I-V curve of the photoconductive element is tangent to the I-V curve of the negative resistance element at one point and intersects the I-V curve of the negative resistance element at a second point. The current and/or voltage of the device changes abruptly upon irradiation of the photoconductive element with light having an intensity slightly greater than or slightly less than the light intensity corresponding to the I-V curve of the photoconductive element according to whether the I-V curve of the photoconductive element is tangent to the I-V curve of the negative resistance element on the concave downward side or on the concave upward side.

2 Claims, 9 Drawing Figures

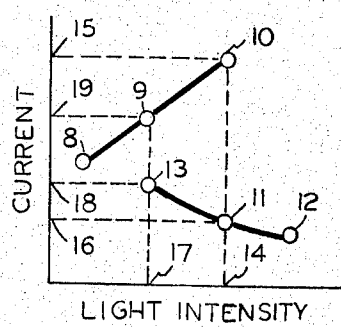




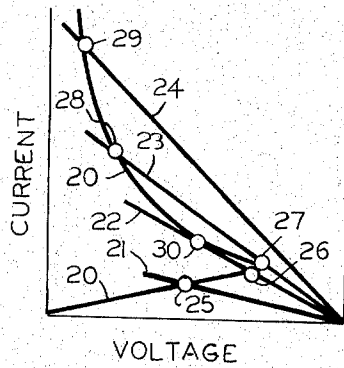
**FIG. 1**



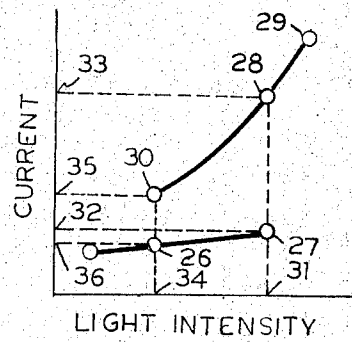
**FIG. 2**



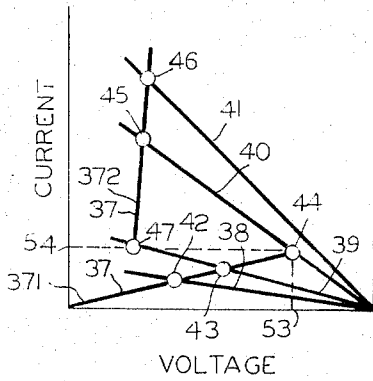
**FIG. 3**



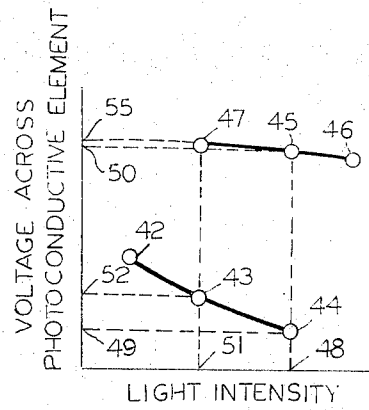
**FIG. 4**



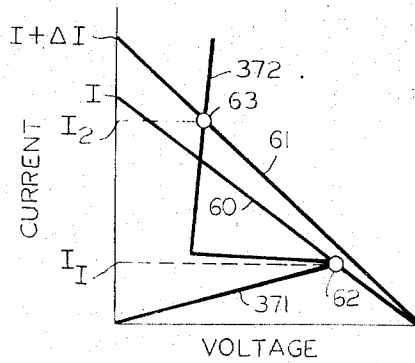
**FIG. 5**



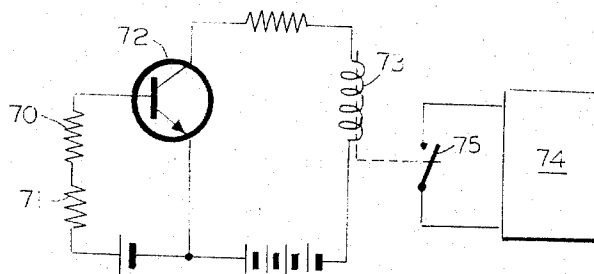
**FIG. 6**



**FIG. 7**



**FIG. 8**



**FIG. 9**

## LIGHT SENSING DEVICE

This invention relates to a light sensing system and the like, such as a light memory or light detecting device.

A group of materials such as cadmium sulfide, selenium, and zinc oxide are well known to be photoconductive. The main characteristic of photoconductive material is that the electrical resistivity thereof decreases with an increase in the intensity of light irradiating the material. Various literature references have disclosed a light sensing system based solely on the function of a photosensitive element. It has been rather difficult for the prior art to construct a light sensing system which is simple in form yet which operates in a way such that the current or voltage changes abruptly at a predetermined intensity of light irradiating the photoconductive element.

An object of the present invention is to provide a light sensing device in which there is an abrupt change in the current and/or the voltage at a given light intensity.

Another object of the present invention is to provide a light memory device capable of memorizing a prior irradiation of light having an intensity different from a given range of light intensity.

A further object of this invention is to provide a light detecting device capable of amplifying an electric output in response to a slight change in the light intensity irradiated thereon.

These objects are achieved by providing a light sensing device according to the present invention comprising a photoconductive element and a negative resistance element connected in series, the current vs. voltage curve (I-V curve) of said negative resistance element being tangent to the I-V curve of said photoconductive element and intersecting said I-V curve at another point whereby the current of the overall device changes abruptly upon irradiation of said photoconductive element with light having an intensity slightly greater than or less than the light intensity corresponding to said I-V curve of said photoconductive element.

The device can function as a light memory device according to the present invention when the photoconductive element is irradiated with a light having an intensity lower or higher than the specified intensity, the device memorizing by its conductivity that it has been irradiated with light having an intensity higher or lower than said specified intensity.

The device can function as a light detecting device in that the device generates an amplified electric output when said photoconductive element is irradiated with light slightly lower or higher than said specified intensity.

The features and advantages of the present invention will be apparent from the following description and the accompanying drawings wherein:

FIG. 1 is a circuit diagram of an embodiment of the light sensing device according to the invention having a series connected photoconductive element and a negative resistance element;

FIG. 2 is a graph showing the current vs. voltage curve of a thermistor having a positive temperature coefficient of resistance (designated a PTC thermistor in the following description) and the characteristic current vs. voltage curve of a photoconductive element under irradiation of lights of various intensities;

FIG. 3 is a graph showing variation in the current with a change in the intensity of light irradiated on a photoconductive element corresponding to that of FIG. 2;

FIG. 4 is a graph showing the current vs. voltage curve of a thermistor having a negative temperature coefficient of resistance (hereinafter designated an NTC thermistor) and the characteristic current vs. voltage curve of a photoconductive element under irradiation of lights of various intensities;

FIG. 5 is a graph showing variation in the current with a change in the intensity of light irradiated on a photoconductive element corresponding to that of FIG. 4;

FIG. 6 is a graph showing the current vs. voltage curve of a switching diode and the characteristic current vs. voltage curves of a photoconductive element operating under irradiation of lights of various intensities;

FIG. 7 is a graph showing variation in the voltage across a photoconductive element corresponding to that of FIG. 4 with a change in the light intensity;

FIG. 8 is a graph showing the change in the output current due to a slight increase in the light intensity for a novel light detecting device according to the present invention and for a conventional device using only a photoconductive element for purposes of comparison; and

FIG. 9 is a circuit diagram of a remote control tuning switch for TV employing a light sensing device according to the present invention.

The photoconductive element as described herein is defined as an element in which the current increases when the element is exposed to radiation, such as X-rays, ultraviolet rays, visible light or infrared rays. Operable elements include, for example, CdSe elements for X-rays, SnO<sub>2</sub> elements for ultraviolet rays, CdS elements for visible light, and Si elements for infrared rays.

The negative resistance element as described herein is defined as an element in which the current decreases with an increase in the voltage or in which the voltage decreases with an increase in the current. Operable elements are a thermistor having a positive temperature coefficient of electrical resistance (PTC thermistor), a thermistor having a negative temperature coefficient of electrical resistance (NTC thermistor) and a switching diode which converts into a low resistance state from a high resistance state at a given voltage.

Referring to FIG. 1, terminals adapted to be coupled to an external current source are connected to photoconductive element 1 and to negative resistance element 2, and elements 1 and 2 are connected in series.

Referring to FIG. 2, the reference character 3 designates the current vs. voltage curve of a PTC thermistor, one form of the negative resistance element 2, at a constant ambient temperature. The current flowing through the PTC-thermistor increases as the applied voltage increases and there is an accompanying increase in the temperature of the PTC thermistor itself with an increase in the applied voltage. When the temperature exceeds a specified temperature, which depends upon the characteristics of the PTC-thermistor, the current flowing through the PTC-thermistor decreases even if the applied voltage increases because of the PTC characteristics. The I-V curve 3 of the PTC thermistor is curved downwardly and has a negative re-

sistance characteristic, as shown in FIG. 2. The reference characters 4,5,6 and 7 designate the characteristic I-V curves of the photoconductive element 1 for various intensities of irradiated light. The resistance of the photoconductive element decreases with increasing light intensity and the slopes of the characteristic curves become steeper. Operating points of the light sensing system according to the invention are represented by the points of tangency and intersection of the I-V curve 3 of the PTC-thermistor 2 and the I-V curves 4-7 of the photoconductive element 1. As the intensity of the light irradiated on the photoconductive element increases, the operating points vary successively in the order 8, 9, 10, 11, 12 and at the same time the current-flows vary as shown in FIG. 3. The variation in current is characterized by an abrupt change as follows: Since the I-V curve 6 of the photoconductive element is tangent to the peak 10 on a concave-downward side of the I-V curve 3 of the PTC-thermistor and intersects the curve 3 at point 11, the operating point immediately moves to a point 11 from a point 10 as soon as the intensity of light on the photoconductive element exceeds the intensity specified by the curve 6. Consequently, the current flow drops abruptly. On the other hand, as the light intensity decreases from an intensity larger than that specified by curve 7, the operating points move successively in the order 12, 11, 13, 9, 8 along the curve 3. Since the curve 5 is tangent to the I-V curve 3 at the point 13 on a concave-upward side and intersects the curve 3 at point 9 as shown in FIG. 2, the operating point immediately moves from a point 13 to point 9 with a further decrease in the light intensity. Thus, the current increases abruptly.

The above operation will be explained with reference to FIG. 3 wherein the operating points in FIG. 2 are correlated with the points on the curve in FIG. 3 by being given the same numbers. At a light intensity 14, the current drops abruptly from current 15 to a current 16, and at a light intensity 17, the current increases abruptly from a current 18 to a current 19.

The specific light intensities 14, 17 can be predetermined by a selection of characteristics of the PTC thermistor and the photoconductive element.

Referring to FIG. 4, the reference character 20 designates the I-V curve of an NTC thermistor at a constant ambient temperature. The current flowing through the NTC thermistor increases with an increase in the applied voltage and there is an accompanying increase in the temperature of the NTC thermistor itself with an increase in the applied voltage. When the temperature exceeds a specific temperature depending upon the characteristic of the NTC thermistor and the ambient temperature, the current flowing through the NTC thermistor increases even with a decreasing applied voltage because of the NTC characteristic. The I-V curve 20 of the NTC thermistor exhibits a negative resistance characteristic, as shown in FIG. 4. The reference characters 21, 22, 23, 24 designate the I-V curves of a photoconductive element at various light intensities. The resistance of the photoconductive element decreases with increasing light intensity and the steepness of the characteristic curve increases. The operating points of the system are represented by the intersections of the I-V curve 20 of the thermistor and the I-V curves 21-24 of the photoconductive element. As the light intensity of the light on the photoconductive element increases, the operating points vary successively

in the order 25, 26, 27, 28, 29, and at the same time the currents vary as shown in FIG. 4. On the other hand, as the light intensity decreases, the operating points move successively in the order 29, 28, 30, 26, 25 along the characteristic curve 20 of the thermistor.

The variation of current with light intensity is shown in FIG. 5 in which the numbered points on the curves correspond to the operating points in FIG. 4 with the same reference number. At a light intensity 31, the current increases abruptly from a current 32 to a current 33 with a slight increase in the intensity and at a light intensity 34, the current decreases abruptly from a current 35 to a current 36 with a slight decrease in the intensity. The specific light intensities 31 and 34 can be predetermined by a selection of the characteristics of the thermistor and the photoconductive element.

Referring to FIG. 6, the I-V curve 37 is the curve for a switching diode having a negative resistance characteristic such that a high resistance state 371 switches to a low resistance state 372 as the voltage across the diode exceeds a specific value 53. I-V curves 38, 39, 40, 41 are for a photoconductive element having an electric resistance which decreases with an increase in the light intensity. An increase in the light intensities of light falling on said photoconductive element causes the operating points to change successively in the order 42, 43, 44, 45, 46.

The relation between the light intensity and the divided voltage across the photoconductive element of FIG. 6 will be explained with reference to FIG. 7, wherein the reference numbers designate points corresponding to the similarly numbered points of FIG. 6. At a light intensity 48, the voltage across the photoconductive element increases abruptly from a voltage 49 to a voltage 50 with a slight increase in the light intensity. At a light intensity 51, the voltage decreases abruptly from a voltage 55 to a voltage 52 with a slight decrease in the light intensity. The light intensities 48 and 51 can be predetermined by the characteristics of the switching diode and photoconductive element.

A photoconductive element and a negative resistance element connected in series can be used for a photo-sensitive device having an abrupt change in the current and/or voltage across the photoconductive element at a predetermined light intensity of light falling on the photoconductive element.

It has been discovered according to the present invention that a photoconductive element and a negative resistance element connected in series can be used as a light memory device. The memory action is explained with reference to a system consisting of a switching diode and photoconductive element. However, the explanation should not be construed as limitative.

Referring to FIGS. 6 and 7, the switching diode in a high resistance state 371 switches to a low resistance state 372 when the photoconductive element is exposed to a light having an intensity higher than an upper limit 48. A decrease in the light intensity to a range between the upper limit 48 and the lower limit 51 does not cause a change from the low resistance state to the high resistance state. In other words, the switching diode can memorize a previous intensity of light higher than the upper limit 48. Similarly, the switching diode can memorize a previous intensity of light lower than the lower limit 51 in the following way: the switching diode in a low resistance state 372 switches to a high resistance state 371 when the photoconductive el-

ement is exposed to light having an intensity lower than the lower limit 51. Even when the light intensity increases to a range between the upper limit 48 and the lower limit 51, the switching diode does not change from the high resistance state 371 to the low resistance state 372.

The memory state, for example, the memorized high resistance state 371 can be erased by illuminating the photoconductive element with light having an intensity higher than the upper limit 48 or by imposing a voltage higher than the voltage 53 across the switching diode.

The combined system according to the present invention can further be used for a light detection device having a high sensitivity. The detecting action is explained with respect to a device comprising a photoconductive element and a switching diode. However, the explanation should not be construed as limitative.

Referring to FIG. 8, wherein similar reference characters designate curves similar to those of FIG. 6, the curve 60 is an I-V curve of a photoconductive element which is being illuminated with light L having a lower intensity than the aforesaid upper limit 48 of FIG. 7 and intersects the I-V curve of the switching diode in the high resistance state 371 at a point 62. At this moment, the current flowing through a device is  $I_1$ . When the light intensity increases from L to  $L+\Delta L$  which is slightly higher than the upper limit 48, the I-V curve of the photoconductive element is designated by a curve 61 and the operating point moves abruptly from the point 62 to a point 63 in the low resistance state 372. The current flowing through the device under light of an intensity of  $L+\Delta L$  is  $I_2$ . Therefore, a slight change in the light intensity from L to  $L+\Delta L$  results in a current change from  $I_1$  to  $I_2$ . When only the photoconductive element is used, the current flowing through the photoconductive element is I or  $I+\Delta I$  under light intensity L or  $L+\Delta L$ . The increment  $\Delta I$  is much smaller than the difference between  $I_1$  and  $I_2$ . Therefore, the light detecting device according to the present invention amplifies an output current ratio with only a slight increase in the light intensity. Similarly, the device according to the present invention can amplify an output current ratio with only a slight decrease in the light intensity.

In the above explanation, the light detecting action is described as affecting the output current flowing through the device. However, it will be self-evident that the device according to the present invention can easily detect a slight change in the light intensity by using the voltage change across the photoconductive element.

Referring to FIG. 9, the circuit is essentially a common emitter circuit of an npn transistor 72. The present light sensing device consisting of a photoconductive element 70 and an NTC thermistor 71 connected in series is inserted in the base circuit of said transistor 72. Said photoconductive element 70 is sensitive to infrared rays. The light sensing device is designed in the following way: The current flowing through the light sens-

ing device is too small to keep the transistor 72 in an on-state when no infrared light is falling on the photoconductive element 70. The current becomes large enough to convert the transistor 72 from the off-state to the on-state when infrared rays fall on said photoconductive element 70. A relay 73 is connected in the collector circuit of said transistor 72 and is activated by the current which flows when said transistor 72 is in the on-state. When said relay 73 is activated, a switch 75 is closed to operate a tuning circuit 74. The present circuit is characterized by a large difference between currents flowing through the base circuit of said transistor 72 when there is no light and when there is infrared light present, and is capable of providing a reliable switch for remote control.

It will be understood by those skilled in the art that systems according to the present invention can be modified in various aspects without departing from the essence of the invention and within the essential features of the invention as set forth in the claims annexed hereto.

What is claimed is:

1. A light sensing device comprising a photoconductive element and a negative resistance element connected in series, said negative resistance element having an I-V curve, and said photoconductive element having an I-V curve for each intensity of light falling on said photoconductive element, at least one I-V curve of said photoconductive element being tangent to the I-V curve of said negative resistance element at one point and intersecting the I-V curve of said negative resistance element at a second point, whereby the current of said device and/or divided voltage across said photoconductive element changes abruptly upon irradiation of said photoconductive element with light having an intensity slightly greater than or slightly less than the light intensity corresponding to said at least one I-V curve of said photoconductive element according to whether the I-V curve of said photoconductive element is tangent to the I-V curve of said negative resistance element on the concave-downward side or on the concave-upward side.

2. A light sensing device as claimed in claim 1 in which one I-V curve of said photoconductive element is tangent to the I-V curve of said negative resistance element on the concave-downward side, and a second I-V curve of said photoconductive element is tangent to the I-V curve of said negative resistance element on the concave-upward side, whereby the device can act as a light memory device to memorize a previous illumination by a light having an intensity higher or lower than the intensities of the respective I-V curves of said photoconductive element and can act as a light detecting device to generate an amplified electric output when the photoconductive element is irradiated with a light slightly lower or higher than the intensities of the respective I-V curves of said photoconductive device.

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