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I. M. ROSS

2,984,749

ELECTROLUMINESCENT SWITCHING APPARATUS

Filed May 31, 1957

FIG. 1

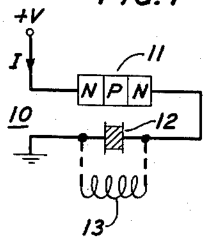


FIG. 2

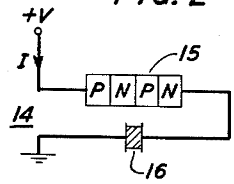


FIG. 3

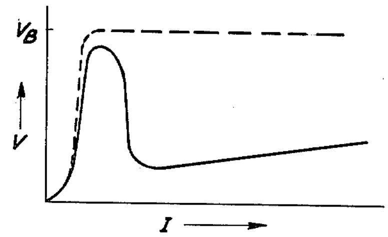


FIG. 4

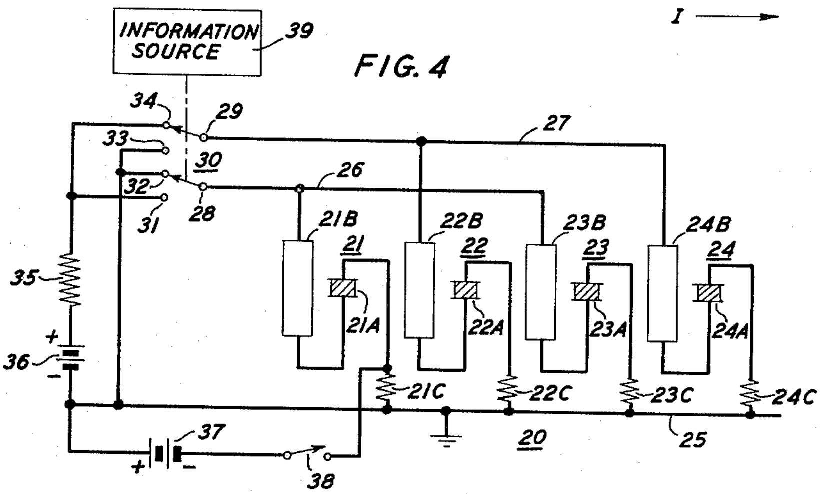
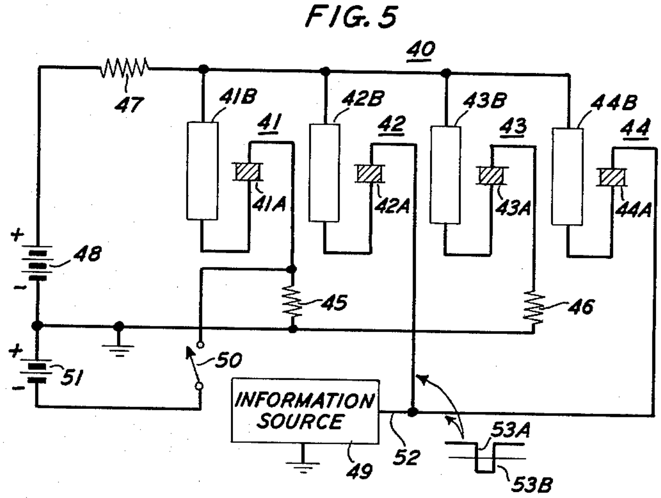


FIG. 5



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ELECTROLUMINESCENT SWITCHING APPARATUS

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5 Claims. (Cl. 250—209)

This invention relates to arrangements in which electroluminescence is used to control the impedance state of a photoconductive element and more particularly to arrangements of this kind which are useful as counting devices.

The theory of electroluminescence is developed in detail in a paper entitled "Electroluminescence," published in the General Electric Review of July 1954. Briefly electroluminescence involves the excitation of luminescence by the application of an electric potential to a crystalline phosphor. Typical phosphors include silicon carbide, zinc sulfide, cadmium sulfide and zinc sulfoselenide.

It has been suggested hitherto that it is possible to utilize the luminescence provided by an electroluminescent cell to control the impedance of a photoconductive element. However, one feature of the present invention is the series combination of an electroluminescent cell and a phototransistor having both a quantum efficiency greater than unity, to be called gain, and a breakdown characteristic whereby the combination provides an improved switching characteristic. A quantum efficiency greater than unity denotes that each photon incident on the photoconductive element reduces the resistance of the element to such an extent that there results an increase in current through the element of more than a single electron. The expression "breakdown characteristic" as applied to the phototransistor denotes that the element includes a p-n rectifying junction which when biased in reverse provides a high resistance until the bias across it is raised to a value in excess of a characteristic value, after which it provides a low resistance.

Moreover, it is in accordance with the present invention to employ an array of electroluminescent cells in combination with an array of phototransistors having gain and a breakdown characteristic to achieve apparatus which is similar in action to the stepping devices described in my copending applications Serial No. 516,521, filed June 20, 1955, and Serial No. 579,006, filed April 18, 1956, which are suited for use as an electronic counter.

A device of this kind involves an array of sections which can individually be placed in a conducting condition in a prescribed order. To insure that individual sections will be energized in a prescribed order, it is generally advantageous to prime in some fashion the section to be energized next before deenergizing a particular section. In the devices described such priming action is achieved by incorporating all the stepping sections in a single semiconductive crystal and appropriately controlling the positions and geometries of the individual sections. However, as a result the fabrication of such devices is relatively complex, particularly if a very large number of stepping sections is sought to be included in the one device.

In the preferred form of the present invention, the priming action is achieved by including in each stepping section both an electroluminescent cell and a phototransistor having gain and a breakdown characteristic and positioning the electroluminescent cell in a manner that when energized it will illuminate both the phototransistor in its own stepping section as well as the phototransistor in the stepping section which it is desired to energize next.

In a preferred embodiment of the invention, there is provided a plurality of stepping sections, each of which includes an electroluminescent cell, a phototransistor, and a load. The stepping sections form two sets arranged so that there will be activated alternately a member from each set. Each electroluminescent cell is positioned so that when energized it will illuminate the phototransistor of the stepping section to which it belongs and the phototransistor of the stepping section to be activated next in the other set.

It will be characteristic of a counter of this kind that visual reading of the number counted is feasible. Moreover, the use of light as the priming premium makes possible electrical isolation between the separate elements of the counter and as a consequence greater flexibility both in design and in the use to which the counter can be put.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawing in which:

Each of Figs. 1 and 2 shows a series combination of an electroluminescent cell and a phototransistor having both gain and a breakdown characteristic to provide a switch in accordance with one feature of the present invention;

Fig. 3 shows the voltage-current characteristic of the arrangement shown in Fig. 1, and

Figs. 4 and 5 show different forms of a counter incorporating a plurality of switches essentially of the kind shown in either Figs. 1 or 2.

With reference now to the drawing, the switch **10** shown in Fig. 1 comprises a series combination of a phototransistor **11** having both gain and a breakdown characteristic and an electroluminescent cell **12**. The electroluminescent cell may be of the kind described in the aforementioned General Electric Review paper. The element **11** in this case is shown as an NPN phototransistor, for example, of the kind described in United States Patent 2,641,713, which issued on June 9, 1953. In is characteristic of a phototransistor of the kind shown that when unilluminated it will have a voltage-current characteristic of the kind represented by the broken line **1** in in Fig. 3 where the voltage V and current I are measured as shown in Fig. 1. It can be seen that there is a voltage V_B at which the resistance of the element changes abruptly from a high value to a low value. This corresponds to the breakdown voltage of the reverse-biased rectifying junction in the phototransistor. If the series resistance in the dark before breakdown of the phototransistor is made to be much higher than the series resistance of the electroluminescent cell, only a small fraction of the voltage applied across the switch will appear across the cell and its light output will be low. However, when that portion of the applied voltage which is developed across the phototransistor exceeds the breakdown voltage, its series resistance decreases to value which is small in comparison to the resistance of the cell. Thereupon, a larger fraction of the applied voltage will appear across the cell and its light output can be high. If a significant portion of this light output is made to illuminate the phototransistor, its series resistance will remain low, even though the voltage developed across the phototransistor is reduced below the value originally needed to initiate breakdown. Because the phototransistor provides gain, i.e., it has a quantum efficiency greater than unity, the condition of low phototransistor resistance and high cell light output may now be maintained with a voltage applied to the switch much less than needed to produce this state initially. In particular, there will result for the combination a voltage-current relationship of the kind represented by the solid line in Fig. 3. It will be characteristic that the low-resistance high-light output state of the switch will continue so long as the voltage applied to the switch is sufficient to maintain the flow of current therethrough at a minimum sustain value.

It is necessary to utilize a phototransistor characterized by gain to achieve the solid line characteristic shown, since compensation must be provided for losses inherent in the electroluminescent cell. If there be used a photoconductive element with a quantum efficiency less than unity, i.e. with no gain, it is necessary to keep the voltage applied to the switch above the breakdown value for substantially as long as the low-resistance high-light output state is to be maintained.

The circuit described can be operated with either direct current or alternating current. In the former case, it is usually advantageous to use monocrystalline phosphor material in the electroluminescent cell described in the aforementioned General Electric Review paper. With alternating currents it is usually advantageous to use polycrystalline phosphor material instead. Moreover, in this latter instance, it is important to provide that the steady component of the light output of the cell (an alternating current cell provides a light output which has an alternating component superimposed on a steady component) is sufficiently high and the minority carrier storage in the phototransistor sufficiently long, that the phototransistor does not resume its low impedance state in the interval when the applied voltage is passing through zero during a reversal in polarity.

An alternating current switch may be made frequency sensitive by shunting an inductor **13** across the cell as is shown by the broken line of Fig. 1. In this case, appreciable voltage can be developed across the cell and a high-light output produced only when the applied alternating voltage has a frequency close to the resonant frequency of the parallel LC circuit formed by the inductor and the cell capacitance.

Fig. 2 shows a switch **14** with characteristics similar to that of Fig. 1 in which there is substituted for the three layer phototransistor a four layer PNPN phototransistor of the kind described in a paper in the Proceedings of the I.R.E., 44, 1174 (1956), entitled "PNPN Transistor Switches." Accordingly, the switch comprises a PNPN diode **15** in series with an electroluminescent cell **16** positioned to illuminate the middle junction of the diode which is the one biased in reverse by the applied voltage. As is described in the above-identified paper, such a diode, even when unilluminated, has a voltage-current characteristic similar to that shown by the solid line of Fig. 3. However, the presence of the electroluminescent cell serves to accent the breakdown characteristic. Additionally, as will be discussed below, the electroluminescent cell in such a switch can be used to prime a selected one of a plurality of switches since the illumination of the reversed-biased junction in a PNPN diode of this kind reduces the voltage necessary for breakdown.

In this switch, unlike that of Fig. 1, it is not ordinarily feasible to have the voltage applied across the diode reverse polarity without having the switch return to a high-resistance low-light output state. This results because of the necessity for maintaining a sustaining current through the diode in a given direction for as long as the low-resistance high-light output state is to continue.

In Fig. 4 there is shown a counting device **20** which utilizes a plurality of stepping sections each of which includes a switch of the kind shown in either Figs. 1 or 2. In particular, the counter shown includes only four sections **21**, **22**, **23** and **24**, although additional sections may be added as desired. Each section includes serially connected a load, an electroluminescent cell, and a phototransistor having both gain and a breakdown characteristic. The phototransistor may be either a three layer phototransistor as in the switch of Fig. 1, or a four layer phototransistor as in the switch of Fig. 2. For convenience, each of these circuit elements is being designated by the reference numeral of the section of which it is a part followed by A for the cells, B for the phototransistors, and C for the loads. The various sections form two distinct sets, with alternate sections in the same set and successive sections in different sets. Accordingly, sections **21** and **23** form one set, sections **22** and **24** the other set. Each of the cells **21A**, **22A** and **23A** is positioned so that when energized it will illuminate to a significant extent only the photoconductive element of its own section and the photoconductive element of the succeeding section. Mirrors or other reflectors or transparent light guiding rods may be used to effect better this end, although none are shown in the counter illustrated. The cell **24A** of the last section of the counter typically is adjusted to illuminate the element **21B** of the first section of the counter as well as element **24B**, so that a ring counter is achieved. In such a ring counter, section **21** can be considered as succeeding section **24**. In a ring counter, it is necessary to have an even number of stepping sections. If it is desired to count no higher than the number of sections provided, it becomes unnecessary to insure continuity of advance from the last section to the first section and cell **24A** would not illuminate element **21B**. Each of the load resistances represents an appropriate utilization means, its exact nature being dependent on the use to which the counter is put. If desired, such loads may be eliminated and the output information read out by examination of the light output of the cells, as, for example, by the operator visually. In a ring counter, provision typically is made to connect other higher order counters in tandem. To this end each transfer from section **24** to section **21** would be made to supply a pulse to a higher order counter.

All of the sections have one of their ends interconnected to a point of reference potential. This is achieved by connecting one end of each section to the lead **25** which is at ground potential. All of the sections of a given set have their other ends interconnected. This is achieved by connecting the other end of each of sections **21** and **23** to the lead **26** and the other end of each of sections **22** and **24** to the lead **27**. Leads **26** and **27** in turn are connected to terminals **28** and **29** of switch **30**, which is shown for convenience schematically as a double pole double throw mechanical switch but typically would be electronic in nature. Switch **30** is also provided with terminals **31**, **32**, **33** and **34**. Terminals **31** and **34** are each connected serially through a lockout resistor **35** to the positive terminal of the direct current source **36**. Terminals **32** and **33** are each connected to the lead **25** which connect to the negative terminal of the direct current source **36**. The switch is controlled by an information source **39**. The magnitude of the voltage developed by source **36** is made sufficient to break down a phototransistor which is illuminated to any substantial extent. Successive pulses from the information source are made to interconnect terminals **28**, **29** alternately between terminals **31**, **33** and terminals **32**, **34**, respectively.

Before discussing the technique of initiating the counting action or resetting the counter, it will be convenient to discuss the stepping operation. With the switch **30** in the position shown, assume that section **22** is in the low-resistance high-light output state. In this case the light from cell **22A** is at a high level and is shining on both phototransistors **22B** and **23B**. If now the switch **30** is reversed in a time short to the lifetime of minority carriers in the intermediate zone of the phototransistor **23B** or the decay time of the luminescence of cell **22A**, whichever is the longer, then section **23**, and not section **21**, will go into the low-resistance high-light output condition. Section **23** will be favored because of the priming effected by the incidence of light on the phototransistor **23B** which reduces its effective breakdown voltage. Moreover, after section **23** has broken down and appreciable current starts to be drawn, the voltage drop across the lockout resistance 35 lowers the magnitude of voltage which is developed across the individual sections. For effective lockout action it is important that the resistance of the load in each stepping section be appreciably less than that of the lockout resistor. This reduced magnitude can readily be made to be insufficient to break down any element not previously broken down. In this way, it is possible to insure that under the control of input information successive sections selectively will be transferred to the low-resistance high-light output state.

It is, of course, necessary to provide that the counting action begin in a predetermined manner. Typically, it will be convenient to treat section 21 as the zero and to begin counting from it. To this end, it is important to be able to reset the counter so that section 21 is at the low-resistance high impedance state at the start of each new counting cycle. This can be readily achieved by providing a reset switch 38, as shown, which when closed inserts voltage supply 37 into the circuit of section 21. This reset switch can be closed manually by the operator or more elaborate provision can be made if desired. It is further necessary to insure that switch 30 is set appropriately so that voltage supply 36 will be in series aiding relation with voltage supply 37 while the switch 38 is closed. This can readily be achieved. The magnitude of the voltage developed by voltage supply 37 should be such that when combined with that provided by voltage supply 36, breakdown of element 21B, even if then unilluminated, and switching of section 21 to the low resistance high-light output state is insured. When section 21 is so switched, each of the other sections necessarily will be put in the high-resistance low-light output state because of the action of the lockout resistance 35. It is desirable to keep the switch 37 closed only during the resetting operation since it must be open to permit stepping from section 22 to section 23 during the regular counting.

In Fig. 5 there is shown a modified form of the counter of Fig. 4. This counter 40, too, has been shown with four stepping sections, 41, 42, 43 and 44, each of which includes a switch which may be of the kind shown in either Fig. 1 or Fig. 2, comprising an electroluminescent cell A and a phototransistor B having both gain and a breakdown characteristic. Sections 41 and 43 form one of two sets, sections 42 and 44 the other. Loads 45, 46 may be provided in sections 41, 43, respectively, for control of appropriate utilization means. Alternatively, as previously discussed, output information may be obtained by ascertaining which of the cells is in a high-light output state. This can be done visually by the operator, or additional light sensing apparatus may be provided.

In this arrangement, it will be characteristic that both the leading edge and the trailing edge of each information pulse will initiate stepping action, so that each pulse will advance the low-resistance high-light output state two stepping sections. It is for this reason that loads need to be provided only in alternate sections of the array. Each of the stepping sections has one end connected by way of the lockout resistor 47 to the positive terminal of the voltage supply 48. The considerations discussed in connection with the counter of Fig. 4 regarding the relative values of the lockout resistance and the load are again applicable. Each of stepping sections 41 and 43 has its other end connected to the negative terminal of the voltage supply 48 which is at the ground potential. Each of stepping sections 42 and 44 has its other end connected to ground potential by way of the information source 49 which supplies the series of pulses to be counted. The information source is designed so that each incoming pulse to be counted swings the potential at this end of each stepping section from a level below that of ground to a level above ground.

The counter is also provided with a reset switch 50 which operates in the manner of the reset switch included in the counter of Fig. 4. In particular, this switch is closed momentarily before the start of each counting cycle. The closing of this switch has the effect of inserting voltage supply 51 in series-aiding relationship with voltage supply 48 selectively across stepping section 41. This combined voltage is made large enough to insure the switching of this section to a low-resistance high-output state and all other sections to a high-resistance low-light output state.

As discussed above, the information source 49 is designed to provide that the pulses to be counted are negative. In particular, in the absence of a pulse to be counted, lead 52 is maintained at a potential above ground while in the presence of a pulse, lead 52 is at a potential below ground. In particular, with the passage of the leading edge 53A of the first pulse, there is increased the total voltage applied across sections 42 and 44 since the negative pulse adds to the voltage applied by the voltage supply 48. This total is made sufficient to provide for selective breakdown of the phototransistor 42B which is being illuminated by the cell 41, and, as a consequence, switch 42 is transferred momentarily to the low-resistance high-light output state. With the passage of the trailing edge 53B of the input pulse, there is reduced the voltage applied across section 42. In particular, since the potential on lead 53 is positive, the effect of voltage supply 48 is reduced and the voltage across the switch 42 may be reduced below the value needed to maintain this switch in its low-resistance high impedance state. As section 42 is transferred back to the high-resistance low-light output state, section 43 will be stepped selectively to the low-resistance high-light output state. This occurs because with the return of section 42 to a high resistance, the voltage provided by supply 48 will be developed essentially entirely across sections 41 and 43, and this voltage is made sufficient to break down whichever of these sections has been appropriately primed, which in this case is section 43.

It is to be understood that the specific embodiments which have been disclosed are merely illustrative of the general principles of the invention. Various other arrangements may be devised by one skilled in the art without departing from the spirit and scope of the invention.

In particular, it should be feasible to employ a wide variety of phototransistors so long as they exhibit gain and a satisfactory breakdown characteristic. Moreover, two or more phototransistors may be incorporated into one semiconductive crystal.

Additionally, it should be possible to employ a wide variety of electroluminescent cells. Basically, all that is intended by the term as used herein is a unit which can be turned off and on at a speed appropriate to the counting rate desired and which has a high efficiency of conversion of electrical energy into light of a wavelength useful for influencing the conductivity of the phototransistor.

What is claimed is:

1. Apparatus for counting input electrical pulses comprising a plurality of switches forming two circuits, each switch comprising serially connected electroluminescent means and a phototransistor having gain and a breakdown characteristic, each of said electroluminescent means being positioned to illuminate the phototransistor of its switch and the phototransistor of one switch in the other circuit, a first pair of terminals between which each switch of the first circuit is connected, a second pair of terminals between which each switch of the second circuit is connected, voltage supply means, and means under the control of electrical input information for interconnecting the voltage supply means alternately across the two pairs of terminals.

2. Apparatus comprising a plurality of switches form-

ing two sets, each switch comprising serially connected electroluminescent means and a phototransistor having gain and a breakdown characteristic, each of said electroluminescent means being positioned to illuminate the phototransistor of its switch and the phototransistor of a switch in the other set, means forming a point of reference potential to which one end of each switch is connected and means forming two points of variable potential, the other end of each switch of the respective sets being connected to different ones of said two points, and means under the control of the input electrical pulses for establishing alternately a higher potential on one of the two points than the other.

3. In combination, a plurality of stepping sections, each comprising a phototransistor exhibiting gain and a breakdown characteristic and electroluminescent means, the plurality of stepping sections forming two sets, each electroluminescent means being positioned so that when energized it illuminates both the phototransistor in its stepping section and a phototransistor in a stepping section of the other set, first voltage supply means and a lockout resistor serially connected in each of the stepping sections, and input means supplying electrical pulses inserted serially in the stepping sections of only one of the two sets.

4. A counter for electrical pulses comprising a plurality of counting sections each comprising an electroluminescent cell and a phototransistor, one end of each section being connected to a point of reference potential, the other end being connected to one of two input leads, the ends of successive counting sections being connected to different ones of the two leads, each phototransistor being optically coupled to the cell in its associated counting section and the cell in the preceding counting section whereby such phototransistor may be primed by the cell in the preceding counting section, a lockout resistor, and

a source of steady potential of magnitude sufficient to initiate breakdown in a primed phototransistor, and means under the control of the input pulses to be counted for connecting said separate input leads alternately between a point substantially of reference potential and a point of potential fixed by said source.

5. A counter for electrical pulses comprising a succession of counting sections, the first set of alternate counting sections including an electroluminescent cell, a phototransistor and a load, the second set of alternate counting sections including an electroluminescent cell and a phototransistor, one end of each counting section being connected to a common lead, the other end of the first set of alternate sections being connected to a point of reference potential and the other end of the second set of alternate sections being connected to an input lead, each phototransistor being optically coupled both to the electroluminescent cell in its counting section and to the electroluminescent cell in the preceding counting section, a series combination of a lockout resistance and a steady voltage source connected between said common lead and point of reference potential, and means for applying electrical pulses to be counted to said input lead.

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