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Umeda et al.

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[45] **Mar. 5, 1974**

[54] **VOLTAGE INDICATOR EMPLOYING A RESISTIVE NETWORK AND LIGHT EMITTING DIODES**

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[21] Appl. No.: **135,689**

[30] **Foreign Application Priority Data**

Apr. 20, 1970 Japan 45/32992

[52] **U.S. Cl.** ..... **324/122,** 324/96, 340/324 R, 340/378

[51] **Int. Cl.** **G01r 13/02,** G01r 31/00

[58] **Field of Search** ..... 324/96, 122, 133, 115; 340/378, 324 R; 313/108 A, 108 D; 315/169 TV

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[57] **ABSTRACT**

A voltage indicator employs a plurality of light-emitting diodes and a plurality of resistors suitably combined with each other, and the number of the light-emitting diodes to be energized is increased or decreased with the increase or decrease in the voltage to be indicated. Another voltage indicator has a plurality of columns comprising serially connected resistors and light-emitting diodes, the number of said light-emitting diodes being different by said columns, are connected in parallel with each other between two terminals, and the number of columns having illuminating light-emitting diodes is increased or decreased with increase or decrease in the voltage between said two terminals.

7 Claims, 15 Drawing Figures

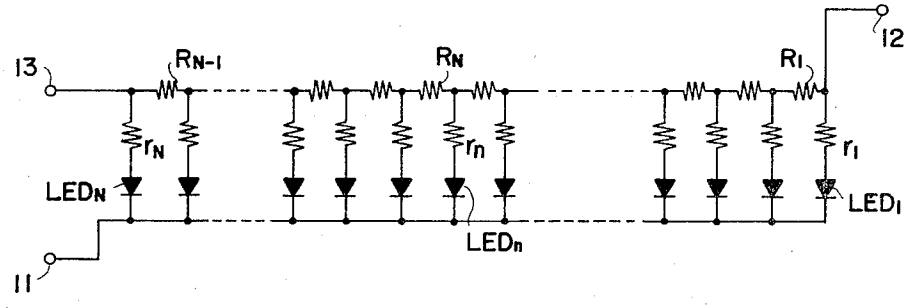


FIG. 1

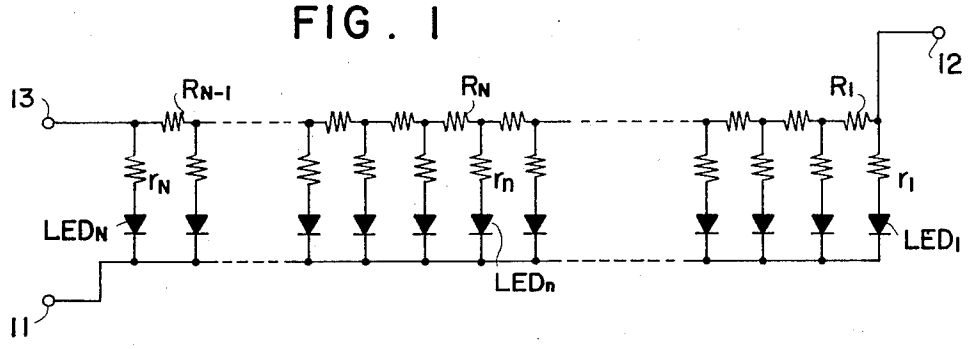


FIG. 2

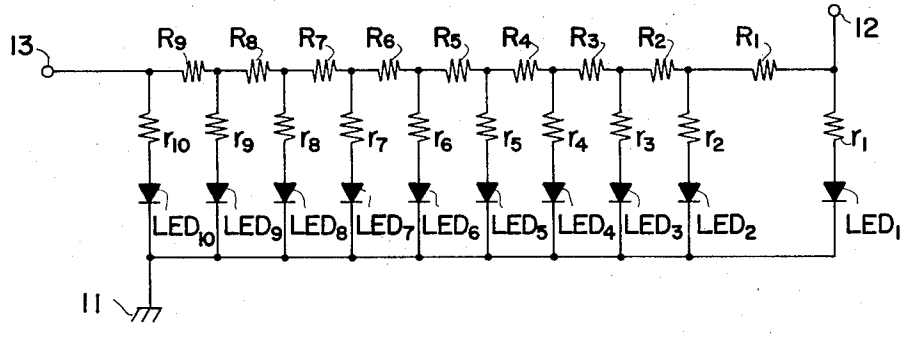


FIG. 3b

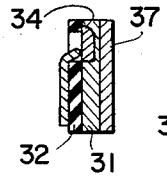
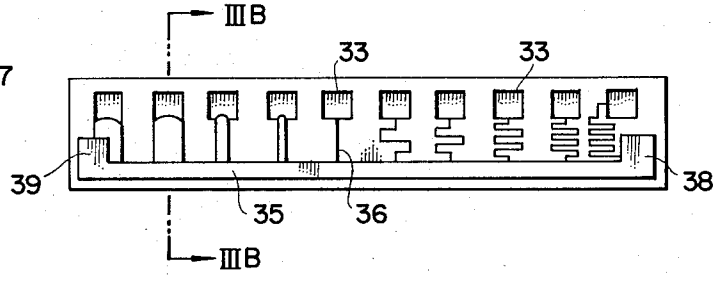


FIG. 3a



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FIG. 4

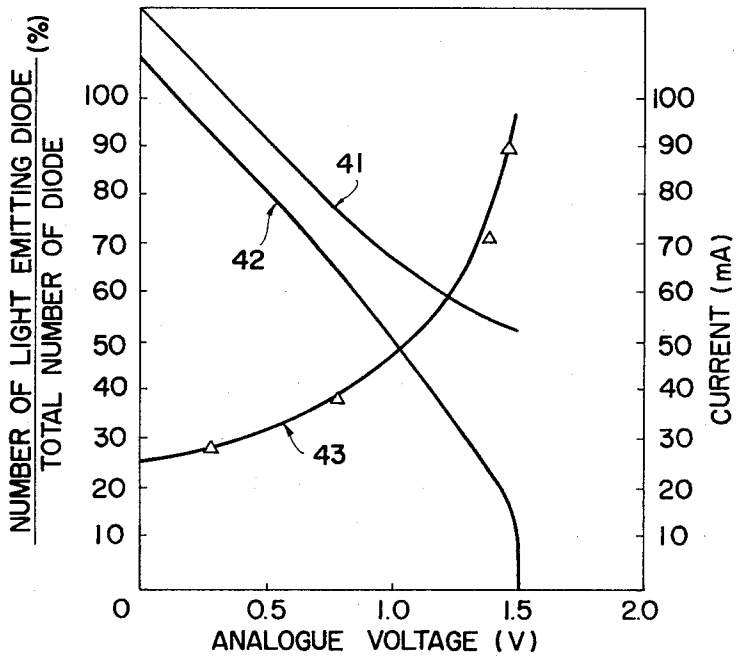


FIG. 5a

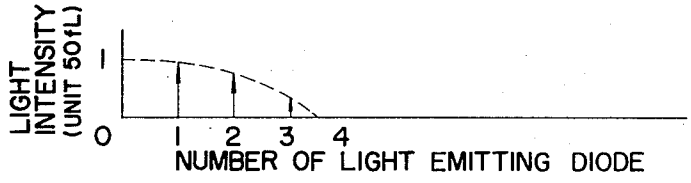


FIG. 5b

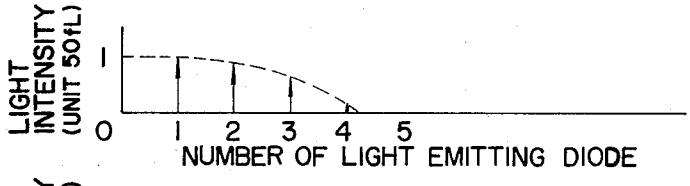


FIG. 5c

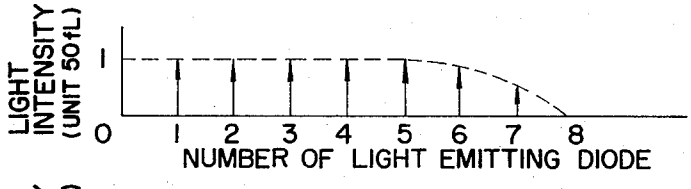
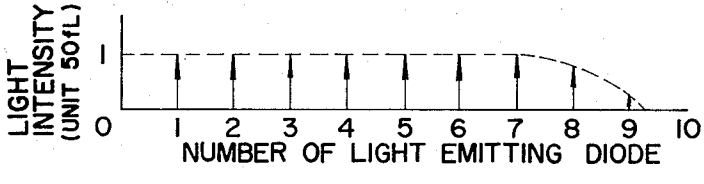


FIG. 5d



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FIG. 6

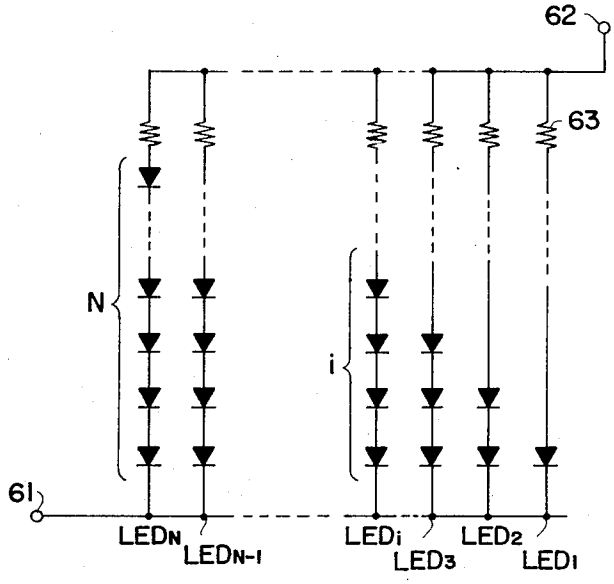
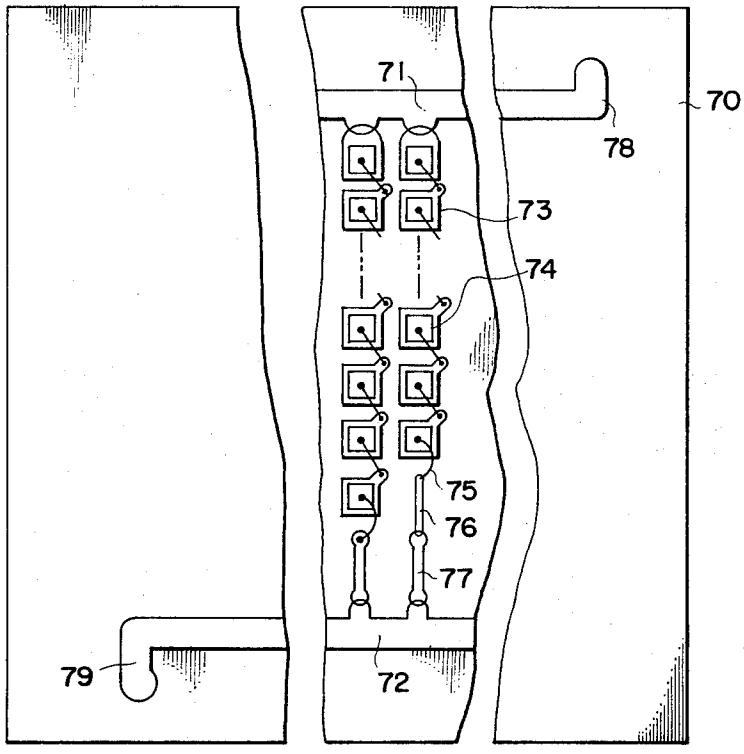


FIG. 7



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FIG. 8

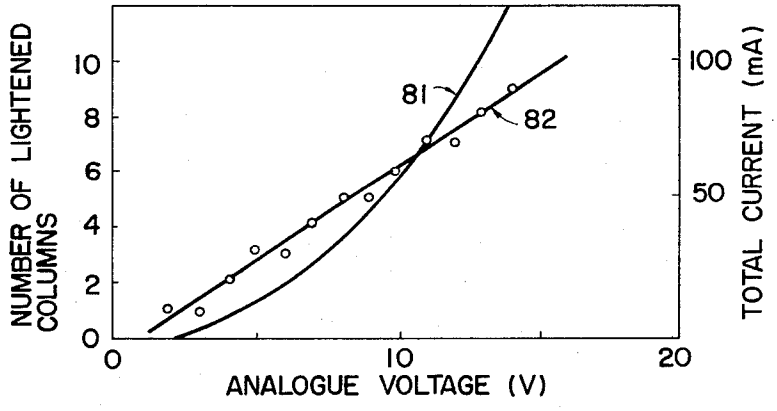


FIG. 9a

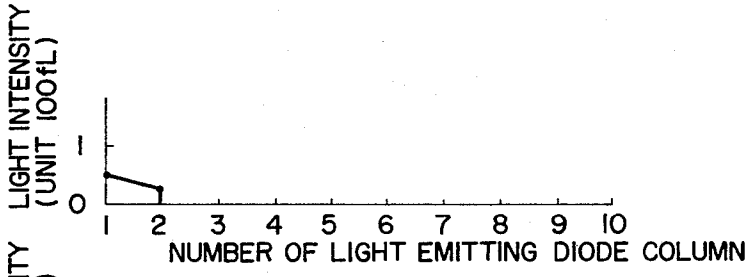


FIG. 9b

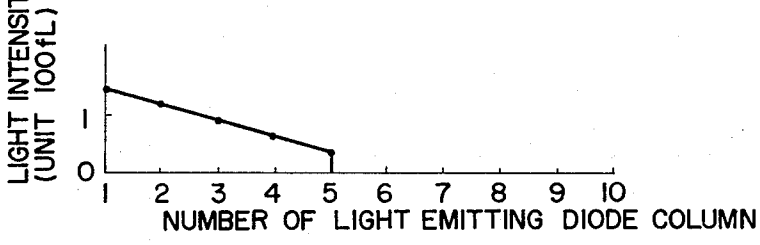
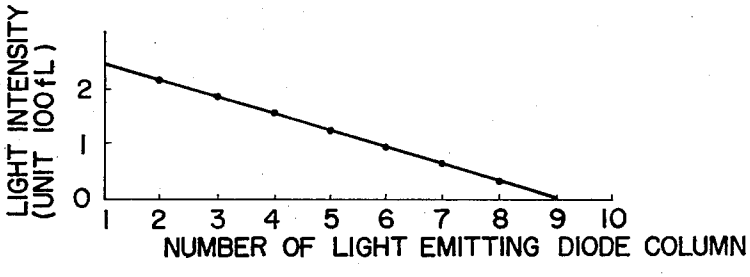


FIG. 9c



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VOLTAGE INDICATOR EMPLOYING A RESISTIVE NETWORK AND LIGHT EMITTING DIODES

This invention relates to an analog voltage or current indicator such as tuning indicator utilizing a light-emitting semiconductor element.

The electrokinetic meters, magic-eye indicators and the like are known as simple forms of indicators like a tuning indicator used for the indication of analog voltage or current. These conventional indicators have drawbacks. For example, the electrokinetic meter is of mechanical construction and hence the mechanical parts are inevitably worn over a period of time and the meter is easily affected by mechanical shock or vibration. The magic-eye indicator, on the other hand, requires heater power and high voltage and is lacking in the mechanical strength and has a short life time because of its use of vacuum tubes. Nevertheless, in the prior art, no practical solid state indicator has been available in place of these conventional indicators.

In view of the foregoing, a general object of this invention is to provide a solid state voltage indicator of robust construction, having a semipermanent life and operably better than the electrokinetic meter, magic-eye indicator and the like.

With the above object in view, the present invention offers a voltage indicator comprising a plurality of light-emitting diodes connected in parallel with each other by way of dividing resistors wherein the number of said diodes to be energized is changed with a change in the voltage to be indicated.

FIGS. **1** and **2** are basic equivalent circuit diagrams showing a voltage indicator of this invention.

FIG. **3***a* is a plan view showing a concrete example of a voltage indicator developed according to the basic equivalent circuit shown in FIG. **2**, and

FIG. **3***b* is a cross sectional view taken across lines III-B—IIIB in FIG. **3***a*;

FIG. **4** shows the relationship between the voltage applied and the light-emission efficiency in connection with the indicator as in FIG. **3**,

FIGS. **5***a* through **5***d* are diagrams showing the relationship between the position of a diode and the intensity of light emitted from the diode in the indicator as in FIG. **3**,

FIG. **6** is another basic equivalent circuit diagram showing a voltage indicator embodying this invention,

FIG. **7** is a diagram showing a concrete example of voltage indicator developed according to the basic equivalent circuit shown in FIG. **6**,

FIG. **8** shows the relationship between the voltage applied and the current in connection with the indicator as in FIG. **7**, and

FIGS. **9***a* through **9***c* are diagrams showng the relationship between the position of a diode and the light intensity in connection with the indicator as in FIG. **7**.

Referring to FIG. **1**, there is shown a basic equivalent circuit of an indicator of this invention, wherein the reference **11** denotes a potential reference terminal, LED_1 , LED_2 . . . . LED_n . . . . LED_N are light-emitting diode elements, and r_1 , r_2 . . . . r_n . . . . r_N are resistors connected in series to said light-emitting diode elements, respectively, in such manner that the diode elements correspond to the resistors by suffixes. The references R_1 . . . . R_n . . . . R_N represent dividing resistors connected between terminals **12** and **13** whereby an impedance ladder network is formed. Among these resistors, the one connected between the resistors r_n and r_{n+1} is indicated by R_n. It is assumed that the value of the suffix is increased toward the terminal **13** from terminal **12.** A constant forward potential higher than the built-in potential of the light-emitting diode element is applied to the terminal **12.** A voltage to be indicated on the indicator is applied to the terminal **13.** The potential applied to the terminal **13** is to be lower than said built-in potential of the light-emitting diode and is of the same sign as that of the potential applied to the terminal **12** (this potential will hereinafter be referred to as positive potential) or may be a negative potential.

When the terminal **13** stands at zero potential, the diodes LED_1 , LED_2 . . . . LED_n among N-number of diodes ($n<N$) are forward biased, thereby emitting light. Under this condition, the diode $LED_k(n<k<N)$ does not emit light. This phenomenon is not observed in the incandescent lamp. Yet, in the discharge indicator lamp, the above phenomenon takes place because discharge starts at a certain threshold value. In the discharge indicator lamp, however, the discharge starting voltage differs from the discharge terminating voltage and, hence, a hysteresis phenomenon appears and the change in the potential at the terminal **13** cannot unambiguously be indicated. When the potential at the terminal **13** is increased in the positive direction, the number of diodes to be forward biased is increased sequentially toward the terminal **13** from the terminal **12** and thus the diodes which emit light are spread toward the terminal **13** from the terminal **12** (namely, the value of n is increased). When the potential at the terminal **13** is lowered, the number of energized diodes is decreased (namely, the value of n is decreased). This operation is perfectly reverse to the operation effected when the potential at the terminal **13** is positively increased. In other words, the number of illuminating diodes arranged sequentially from the terminal **12** to the terminal **13** accurately indicate the potential applied to the terminal **13.**

In the above operation, the light intensity of LED_1 should not be much different from that of LED_n (or LED_{n-1}) in order to obtain clear indication. To this effect, the values of R_i and r_i must be properly determined. Generally these values are determined according to the relationship : $R_i = R$ and $r_i = R/2\ (N-1+1)^2$. Instead, R_i and r_i may be determined specifically to meet the relationship:

$$R_1 < R_2 < \ldots < R_{N-1} \text{ and } r_1 > r_2 > \ldots > r_N$$

FIG. **2** is a basic equivalent circuit diagram showing a concrete example of an indicator in accordance with this invention. In FIG. **2**, the same circuit elements as in FIG. **1** are indicated by common references.

FIG. **3***a* is a plan view and FIG. **3***b* a cross sectional view illustrating an embodiment of the invention wherein the refernce **31** denotes an n-type $GaAs_{0.6}P_{0.4}$ crystal electron density is 3×10^{16} cm^{-3} formed on a GaAs substrate by a vapor growth technique, and **32** is a SiO_2 layer with a thickness of about 0.5 micron (μ) deposited thereto by thermal decomposition. This SiO_2 layer contains a slight amount of phosphorus. A plurality of 0.5×0.5 mm^2 wide openings **33** are disposed on said SiO_2 layer by a photo-resist process. The reference **34** represents p-type layers selectively diffused at about 800° C for 10 minutes through the openings **33.** The

references **35** and **36** denote resistance layers chiefly comprising chromium. These resistance layers are deposited on the SiO_2 layer by evaporation process. Part of the resistance layers comes in contact with the surface of *p*-type layer **34** beneath the opening **33** and thus serves as the electrodes for the *p*-type layer. The reference **37** denotes an electrode on the side of the *n*-type layer. This electrode is an alloy of Au, Ge and Ni and corresponds to the terminal **11** shown in FIG. **1.** The terminals **38** and **39** correspond to the terminals **12** and **13** in FIG. **1** respectively.

FIGS. **4** and **5***a* – **5***d* show indication characteristics obtained under the following conditions:

$$N = 10$$

$$R_1 = R_2 = \ldots . R_9 = 2\Omega$$

$$r_i = (10 - i + 1)^2\Omega$$

voltage applied to terminal **38** : +2V

analog voltage applied to terminal **39**: (V)

In FIG. **4,** the curve **41** shows the variation of current flowing into the circuit via terminal **38,** and the curve **42** the variation of current flowing out of the circuit via terminal **39.** The abscissa represents the value of analog voltage in volts applied between the terminals **37** and **39,** and the ordinate indicates the values of curves **41** and **42.** The symbol Δ represents the ratio of the number of the lightened diodes versus the total number of diodes. This ratio is obtained through measurements by applying various analog voltages to the terminals. The curve **43** is drawn by linking measured values of the ratio. The values on the curve **43** are indicated in milliamps (mA) on the right of FIG. **4.** FIGS. **5***a* through **5**d show light intensities at analog voltages 0.282V, 0.771V, 1.398V and 1.476V, respectively, applied between the terminals **37** and **39.** The numerals indicated by the side of the abscissa show the number of the light-emitting diodes counted from the side of terminal **38.** The unit of the ordinate is 50f.L, and the size of the arrow shown at each number indicates the light intensity of the corresponding diode.

EXAMPLE 2

FIG. **6** is another basic equivalent circuit diagram showing an indicator embodying this invention wherein the reference **61** denotes a potential reference terminal, and **62** a terminal to which a measuring potential is applied. The light-emitting diode LED_i comprises *i*-number of serially connected elements which are connected in series to resistors **63.**

It is assumed that the built-in potential of each diode is v_D. When the potential applied to the terminal **62** is forward with respect to the light-emitting diode, and the value of this potential is V, all the diode columns **1, 2,** . . . . i satisfying the requirement: $V > iv_D$ (*i* is an integer) are illuminated. The value of *i* is changed with change in the value of V. In other words, the value of V is indicated directly in terms of *i*. That is, the number of light-emitting diodes is uniquely determined by the value of V, and no hysteresis is shown. The range of indicatable V is $v_D < V < Nv_D$.

In FIG. **6,** the purpose of the series **63** of resistance *r* is to let $(i+1)^{th}$ column diodes emit light when the intensity of the i^{th} column reaches a certain specific value (namely, the value of current flowing therein comes to a certain specific value v_D/r). Under this condition, a current $(i-k+1)v_D/r$ flows in the diode of k^{th} ($0 < k < i$) column, and a linear light intensity gradient is present across the first column and the i^{th} column. In case such a luminous difference must be reduced, it is necessary to start making the diode luminous not from 1st column but from M^{th} column. In this arrangement, the range of indicatable V is $Mv_D \leq V \leq 24\ Nv_D$.

FIG. **7** shows the structure of another analog voltage indicator of this invention formed according to the basic equivalent circuit shown in FIG. **6.** In FIG. **7,** the references **78** and **79** are terminals corresponding to the terminals **61** and **62** in FIG. **6.** The reference **70** denotes an insulative substrate, **71** a negative side power supply lead, and **72** a positive side power supply lead. A negative electrode **73** is baked to a ceramic substrate. Zinc is diffused into an n-type $GaAs_{0.6}P_{0.4}$ crystal containing tellurium (electron density 3×10^{16} cm^{-3}) whereby a light-emitting diode element **74** is formed. This diode is bonded to said negative electrode **73** and connected in series to a lead wire **75.** The reference **76** denotes a lead wire, and **77** a resistor connected in series to the diode.

FIG. **8** shows the relationship between the voltage applied and the number of light-emitting diode columns under the condition that the value of resistor **77** is 500 Ω in the voltage indicator shown in FIG. **7.** FIGS. **9***a* through **9***c* show the light intensities of individual diode columns under the condition that the voltages applied to the terminal **79** are 4V , 10V and 14V. In FIG. **8,** the abscissa indicates the analog voltage in volt applied to the terminal **79,** the curve **81** shows the variation in the total current, and the symbol *o* the variation in the number of energized columns measured. The values referred to the ordinate are indicated on the right in FIG. **8,** and the values of variation in the number of energized columns are shown on the left. The curve **82** is drawn by linking the values measured thereof.

In FIG. **9,** the abscissa shows the number which indicates the position of each diode column. In this embodiment, this diode position number is equal to the number of diodes serially connected in the corresponding diode column. The ordinate shows the light intensity in units of 100f.L.

The foregoing embodiments are only examples and the invention is not limited thereto or thereby but various modifications may be made thereof. For example, the polarity used in the above embodiments may be arbitrarily determined.

As has been described above, the voltage indicator of this invention has numbers of advantages and is far better than the conventional indicator. For example, according to this invention, use of heater or high voltage is eliminated, the indicator is small in size and robust in construction, and an unambiguous relationship is maintained between the analog voltage to be indicated and the number of diodes energized.

We claim:

1. A solid state voltage indicator comprising:

a first and a second terminal, to which are applied a constant potential of first polarity and a voltage to be indicated, which is lower than said constant potential of first polarity, respectively;

a plurality of first resistors connected in series between said first and second terminals;

a third terminal, to which is applied a reference potential of second polarity; and

a plurality of combinations, each combination consisting of a light-emitting diode and a second resistor connected in series between said third terminal and each respective interconnecting point of two adjacent first resistors as well as said first and second terminals, said constant potential of first polarity applied to said first terminal being higher than the built-in potential of each of said light-emitting diodes, said second resistors connected to a nearer interconnecting point of two adjacent resistors to said first terminal having a higher resistance,

whereby the number of said light-emitting diodes to be energized is increased and decreased with increase and decrease, respectively, in the voltage to be indicated.

2. A solid state voltage indicator according to claim **1,** wherein said resistor, which is nearer to the second terminal, in said first plurality of first resistors connected in series between said first and second terminals has a higher resistance.

3. A solid state voltage indicator according to claim **1,** wherein all first resistors connected in series between said first and second terminals have a substantially equal resistance R and the second resistor belonging to the $(i-1)^{th}$ interconnecting point of two adjacent first resistors of those connected in series between said first and second terminals, when counted from the side of said first terminal, has a resistance $R/2\ (N-i+1)^2$ where N is the total number of combinations, each of which consists of a light-emitting diode and a second resistor connected in series.

4. A solid state voltage indicator comprising:

first means for receiving a source of input potential, the value of which is to be indicated;

second means, responsive to said input potential applied at said first means, for generating a number of beams of light, the number of beams of light being dependent upon the value of the input potential applied to said first means, said second means including an impedance ladder network connected between said first means and a source of a first reference potential, and wherein said impedance ladder network includes at least one light-emitting diode in at least one arm thereof for generating a beam of light in response to a predetermined value of input potential applied to said first means; and

a source of a second reference potential connected to each arm of said network for biasing said at least one diode with respect to said source of first reference potential, said impedance ladder network including a plurality of interconnected impedance sections, at least one of said sections including a first resistor element and at least one light-emitting diode element connected in series, one of which is connected to said source of a second reference potential, said impedance ladder network further including means for interconnecting each of said sections and for providing a current flow path between said source of a first reference potential and said first means including at least one resistance.

5. An indicator according to claim **4,** wherein the number of said interconnecting means is one less than the number of interconnected sections.

6. An indicator according to claim **4,** wherein said impedance ladder network comprises N sections, the first of which is connected to said source of a first reference potential and the N^{th} of which is connected to said first means and wherein the value r_i of the first resistor element in a particular section i is related to the value of each interconnecting resistance by the relationship $r_i = R/2\ (N-i+1)^2$, R being the value of each interconnecting resistance.

7. An indicator according to claim **4,** wherein said impedance ladder network comrpises N sections, the first of which is connected to said source of a first reference potential and the N^{th} of which is connected to said first means, and wherein the value of the first resistor element in each section decreases from the section connected to said source of a first reference potential toward said first means, while the value of each interconnecting resistance increases from said source of a first reference potential to said first means.

* * * * *