June 11, 1968 G. A. MAY **3,388,255**

SOLID-STATE VOLTAGE-SCANNED DEVICE INCLUDING LONG NARROW
P-N JUNCTION MATERIAL WITH PHOTOCONDUCTORS THEREON

Filed June 22, 1964 5 Sheets-Sheet 1

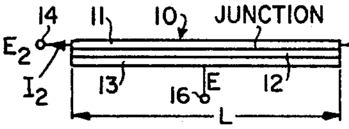

FIG. 1

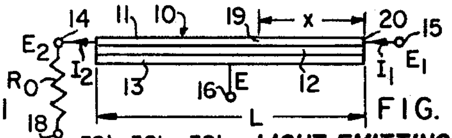

FIG. 2

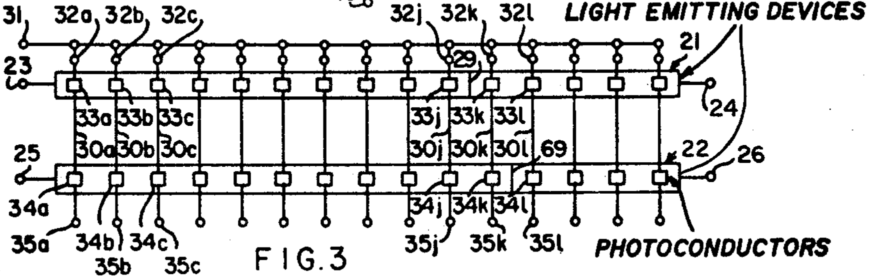

FIG. 3

In Figs. 3 and 4
□= photoconductor

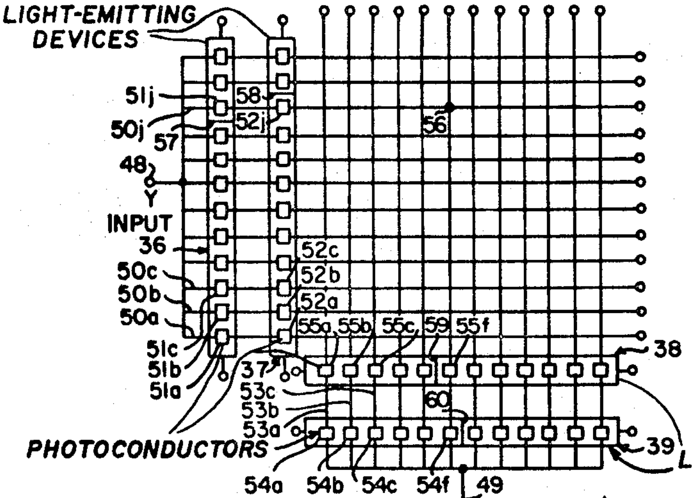

FIG. 4

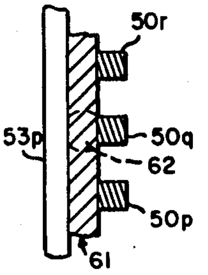

FIG. 5

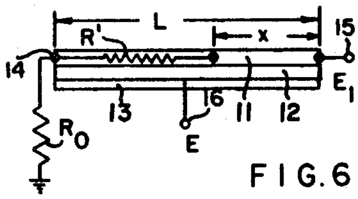

FIG. 6

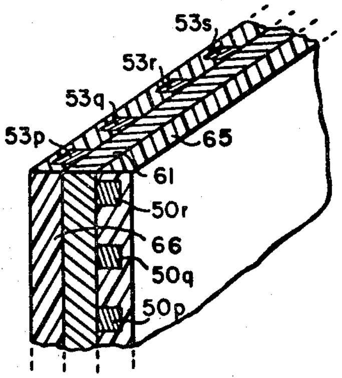

FIG. 7

In Figs. 1, 2, 6,
13= conducting layer
12= semiconductor layer
11= semiconductor layer of
conductively opposite that
of 12

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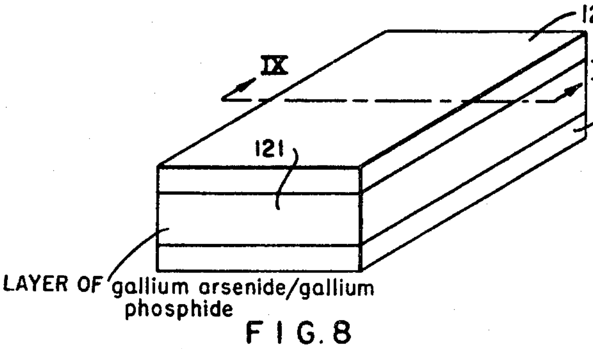

FIG. 8

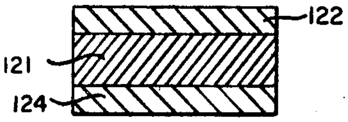

FIG. 9

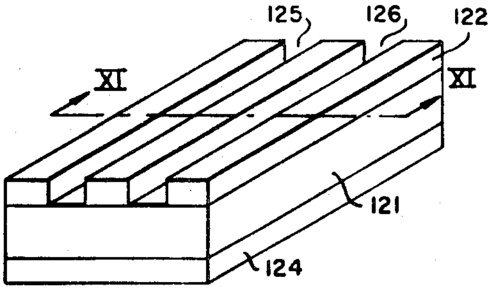

FIG. 10

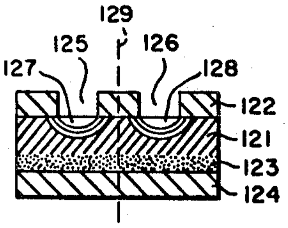

FIG. 11

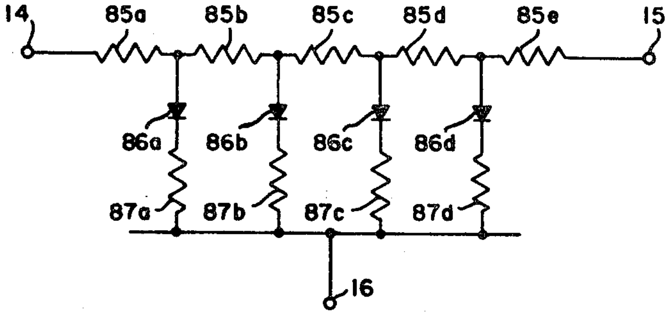

FIG. 12

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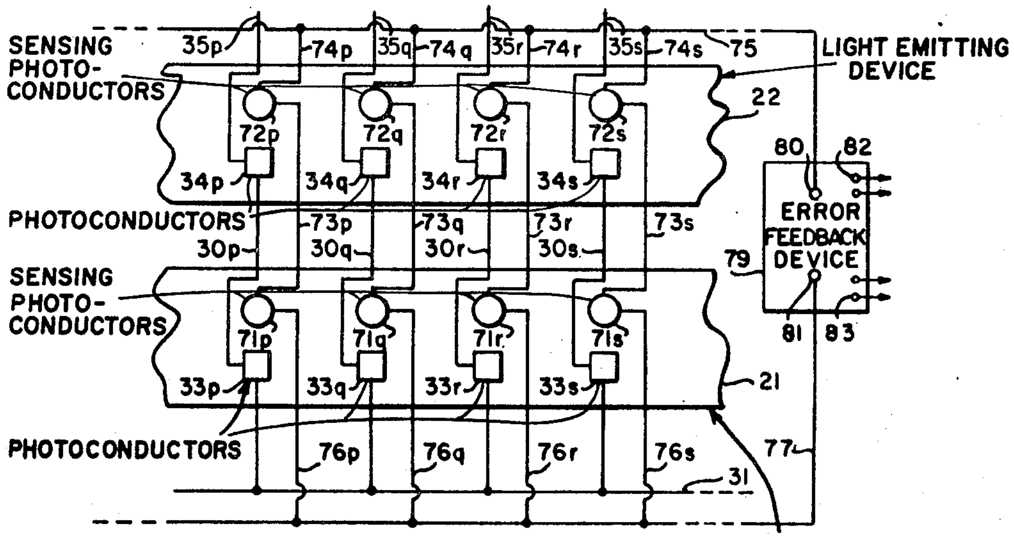

FIG.14

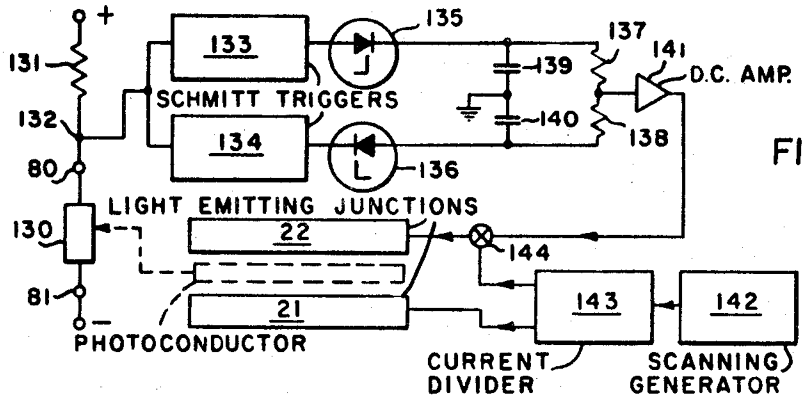

FIG. 15

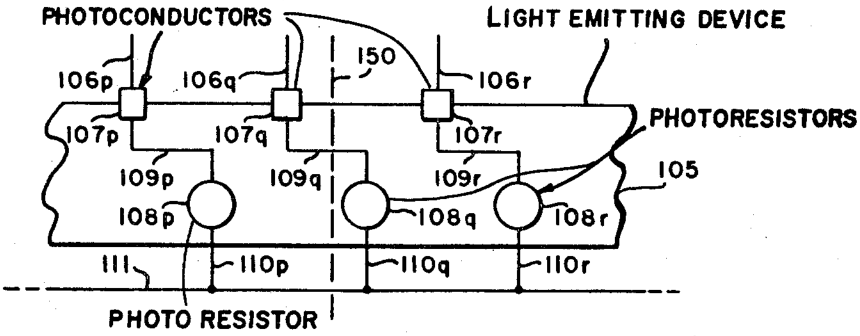

FIG.13

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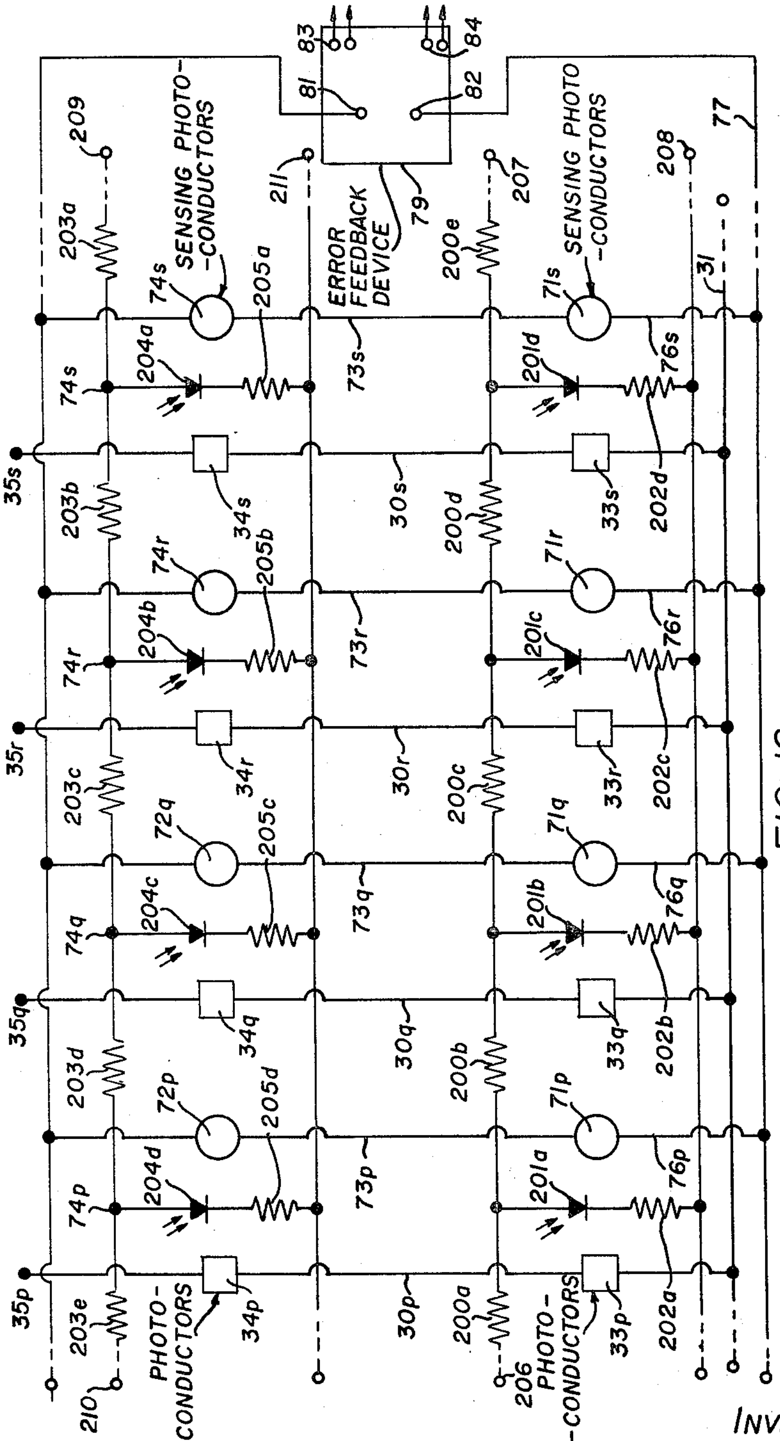

FIG. 16

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SOLID-STATE VOLTAGE-SCANNED DEVICE INCLUDING LONG NARROW
P-N JUNCTION MATERIAL WITH PHOTOCONDUCTORS THEREON

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FIG. 18

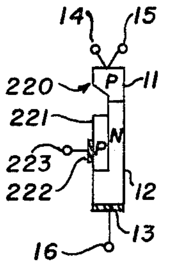


FIG. 17

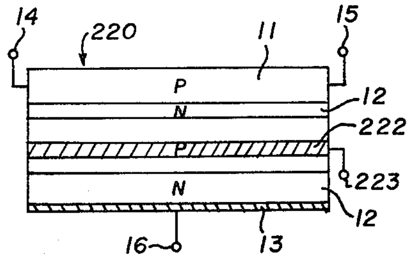


FIG. 20

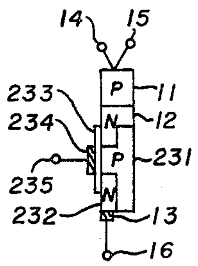


FIG. 19

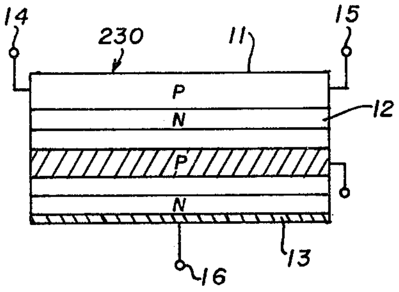


FIG. 22

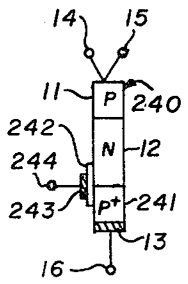
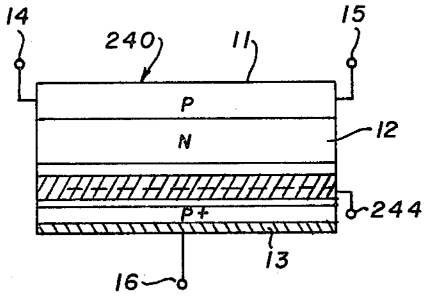


FIG. 21



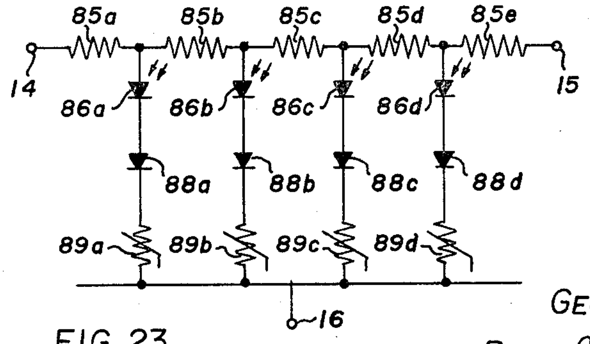


FIG. 23

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United States Patent Office

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Patented June 11, 1968

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SOLID-STATE VOLTAGE-SCANNED DEVICE INCLUDING LONG NARROW P-N JUNCTION MATERIAL WITH PHOTOCONDUCTORS THEREON

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Continuation-in-part of application Ser. No. 339,121, Jan. 21, 1964. This application June 22, 1964, Ser. No. 377,021
24 Claims. (Cl. 250—209)

This invention relates to long, narrow, light-emitting semiconductor junctions and to devices incorporating such junctions.

It is known that certain types of semiconductor junctions are light-emitting. The most common of these are the gallium-arsenide, and the gallium-arsenide and phosphide semiconductor junctions. It is probable that many other light-emitting junctions will be known in the future.

It is an object of the present invention to provide a long, narrow light-emitting semiconductor junction of appreciable length and very small width. Such a junction may be used in a variety of applications. The junction itself may be used as a current indicator analogous to the well known cat's eye indicator. In combination, such junctions can be used as scanning devices, and may be combined with photo conductors in a variety of applications.

In its broadest aspects the present invention provides a long, narrow light-emitting semiconductor junction comprising a conducting layer, a semiconductor layer in ohmic contact with the conducting layer, and a second semiconductor layer of opposite conductivity or doping to the first semiconductor layer and forming a P-N junction with it. All layers are of the same length and the uppermost semiconductor layer (i.e., the one farthest removed from the conducting layer) is provided with a pair of terminals at either end. The conducting layer may also be provided with a terminal.

When voltages are applied to each of the terminals in the above defined device, the junction will emit light along that portion of the device where the voltage on the uppermost layer exceeds the voltage on the conducting layer by the barrier voltage of the junction. If this condition is satisfied, the junction emits light in the vicinity of the end of the uppremost semiconductor layer nearest the terminal at highest potential. As the potential at this terminal of the uppermost layer is increased, more and more of the semiconductor layer emits light until eventually the device is light-emitting over its entire length.

If two such semiconductor junctions are combined so that light is emitted from opposite ends of the junctions, it is possible to combine the two junctions with photoconductors to provide a scanning device. This is preferably accomplished by providing corresponding photoconductors on the two semiconductor junctions, corresponding photoconductors being connected by wires, and applying current to the two junctions so that the light-emitting portion of one semiconductor junction overlaps very slightly the light-emitting portion of the other semiconductor junction, thereby causing only one pair of corresponding photoconductors (one on each junction) in the overlapping portion of the two junctions to conduct current. Therefore an electrical path is completed through a unique pair of photoconductors in the overlapping region, which makes possible the selection of one and only one of the wires for conducting current from an input applied to a first of the selected pair of photoconductors to an output connected to the second of the selected pair of photoconductors.

Furthermore, the output terminals from all the "second" photoconductors in the aforementioned device may be extended as grid wires, combined with grid wires in one or more planes perpendicular to the first plane of the grid wires, and connected to long, narrow semiconductor junctions of the above described type so that a two-dimensional or three-dimensional scanning system is created. The grid wires may be conductors formed by any one of a number of known processes; for example, they can be formed by vapour deposition of a conducting material. Such scanning systems can be used in conjunction with electroluminescent layers for display of information in a manner analogous to display of information on a cathode ray tube. Alternatively, grid wire configurations may be associated with suitable memory storage devices so that an information storage (memory) system such as that used in electronic computers is provided. As a further alternative, the selection of grid wires may be used to create circuit connections in a manner analogous to cross bar switching circuits in the telephone art.

The term "photoconductor" as applied herein, includes various forms of light-sensitive switching elements which display a marked increase in electric conductivity when illuminated. The term "photoconductor" will be understood to encompass photo-diodes, photodiode pairs, photo transistors and cadmium selenide elements, as well as other devices with similar properties. These devices may be macroscopic for some applications while in others they may be vapour deposited or integrated circuits.

According to a further feature of the invention, the scanning systems are arranged so that overlap of more than one pair of corresponding photoconductors which might be caused, for example, by non-uniformities in construction is avoided. This can be accomplished using a suitable error feedback device or by using somewhat more elaborate configurations of photo conductors in connection with the long, narrow light-emitting semiconductor junctions, as will be described in detail below.

The invention will now be described with reference to the accompanying drawings, in which:

FIGURE 1 is a simplified illustration of a long, narrow, light-emitting semiconductor junction according to the present invention;

FIGURE 2 illustrates the junction shown in FIGURE 1 in operation and connected to a suitable terminal resistor;

FIGURE 3 is a simplified illustration of a scanning device incorporating two semiconductor junctions according to the present invention;

FIGURE 4 illustrates a simplified two-dimensional scanning device incorporating four semiconductor junctions according to the present invention;

FIGURE 5 is an expanded section detail view, of a portion of the grid wire array in the scanning device of FIGURE 4;

FIGURE 6 illustrates the junction illustrated in FIGURE 2 with the reverse biased section replaced by an equivalent resistor.

FIGURE 7 is a perspective view, partially in section, of a detail of a further alternative construction of the grid wire configuration of FIGURE 4;

FIGURE 8 is a simplified perspcetive view of the incomplete body of a light-emitting semiconductor junction constructed according to the present invention;

FIGURE 9 is a section view of the junction shown in FIGURE 8 along line IX—IX;

FIGURE 10 shows a simplified perspective view of the body of FIGURE 8 after undergoing a second step in the production of a semiconductor junction according to the invention;

FIGURE 11 is a section view along the line XI—XI of FIGURE 10;

FIGURE 12 illustrates a discrete equivalent of a long narrow P-N junction of the configuration shown in FIGURE 1;

FIGURE 13 illustrates a portion of a hypothetical alternative simplified scanning device constructed according to the present invention;

FIGURE 14 illustrates a portion of a further alternative embodiment of a scanning device constructed according to the present invention;

FIGURE 15 is a schematic block diagram of a control system incorporated in the scanning device of FIGURE 14;

FIGURE 16 illustrates a scanning device of the type described in FIGURE 3 in which the two semiconductor junctions have been replaced by two discreet equivalent circuits.

FIGURE 17 illustrates a light-emitting junction constructed according to the present invention and utilizing a field-effect transistor type structure;

FIGURE 18 is a section view of the device illustrated in FIGURE 17;

FIGURE 19 illustrates a light-emitting junction constructed according to the present invention and utilizing an insulated-gate transistor structure;

FIGURE 20 is a section view of the device illustrated in FIGURE 19;

FIGURE 21 illustrates a light-emitting junction constructed according to the present invention and utilizing a high-field triode structure;

FIGURE 22 is a section view of the device illustrated in FIGURE 21; and

FIGURE 23 illustrates a discreet equivalent of a long narrow light-emitting junction having a constant-current characteristic for individual points along the junction.

A schematic block diagram of the semiconductor junction according to the present invention is illustrated in FIGURE 1. The device, indicated generally by the numeral **10**, includes a conducting base layer **13** preferably of metal; a lower semiconductor layer **12** fixed to the conducting layer **13** and which may, for example, be N-doped; and an upper semiconductor layer **11** which may, for example, be P-doped. The dimensions shown in FIGURE 1 are not exemplary of an actual device constructed according to the invention but are drawn in the manner shown in the interests of clarity. In actual practice all layers **11**, **12** and **13** would be perhaps as much as several inches long and very thin, the thinnest layer being the layer **11**, of the order of a few mils thick. On either end of the semiconductor device **10** are terminals **14** and **15** attached only to the upper semiconductor layer **11**. The lower conductive layer **13** may also be provided with a terminal **16**.

In operation, sources of electric potential are applied to each of the terminals **14**, **15** and **16**. In FIGURE 2, these terminals are shown associated with voltages E_2, E_1 and E respectively.

The light emitting portion length x and the applied voltage E_1 at terminal **15**, and E at terminal **16**, are related by

$$(E+\Delta)=\frac{(E+\Delta)\coth\sqrt{\sigma\rho}x+[E_1-(E+\Delta)]\operatorname{cosech}\sqrt{\sigma\rho}x}{\coth\sqrt{\sigma\rho}x+\sqrt{\frac{\rho}{\sigma}}\Big/\rho(L-x)+R_0} \qquad (1)$$

where:

$$\coth\sqrt{\sigma\rho}x=\frac{e^{\sqrt{\sigma\rho X}}+e^{-\sqrt{\sigma\rho X}}}{e^{\sqrt{\sigma\rho X}}-e^{-\sqrt{\sigma\rho X}}}$$

$$\operatorname{cosech}\sqrt{\sigma\rho x}=\frac{2}{e^{\sqrt{\rho\sigma X}}-e^{-\sqrt{\sigma\rho X}}}$$

Δ=junction barrier barrier voltage for the P–N junction

R_0=terminating resistance

ρ=resistance per unit length of the upper semi-conductor layer **11**

σ=conductance per unit length of the lower semi-conductor layer **12**

L=length of the semiconductor layers **11** and **12**

$$\sigma=\sigma^1\omega$$

where

σ^1=the area conductance

ω=the width of the long narrow junction formed by the two layers **11** and **12**.

In FIGURE 2, the light-emitting portion of the junction is shown emanating from the right and terminating at point **19** which is a distance x from the end **20** of the uppermost semiconductor layer **11**. In this instance the voltage E_1 is greater than the voltage E which in turn is greater than the voltage E_2. As long as the voltage E_1 is less than the voltage E, no current will flow from the uppermost P-layer **11** to the lower N-layer **12**. However, as soon as the voltage E_1 begins to exceed the voltage E applied to the conducting layer **13** by Δ, the barrier voltage, some current is conducted through the P–N junction and light is emitted. The distance x increases as the voltage E_1 increases. If E_1 is sufficiently great, the entire length of the device will emit light.

The P-N junction according to the present invention may be constructed according to known techniques. For example, the lower semiconductor layer may be attached upon a layer of metal and the uppermost P-doped layer may be deposited on the N-layer by diffusion techniques (e.g. in an atmosphere of zinc vapour) or by servo-controlled electrolytic etching, or any other convenient method. In general, the uppermost layer will be considerably thinner than the lower semiconductor layer although both layers, will, of course, be relatively thin. The thickness of the upper layer **11** is preferably in the order of 1 or 2 mils. Either the upper layer or the lower layer may be the P-layer.

A scanning device incorporating a P-N junction constructed as above is shown in FIGURE 3. In this figure, two long, narrow light-emitting semiconductor junctions **21** and **22** are shown in simplified manner as being of unitary construction, although it will be understood that each of the devices **21** and **22** will include the three layers referred to with reference to FIGURE 1. Attached to the uppermost semiconductor layer of each of the devices **21** and **22** respectively are a plurality of regularly spaced photoconductors **33***a*, **33***b*, **33***c*, etc. and **34***a*, **34***b*, **34***c*, etc. Each photoconductor is shielded from all light except light emanating from the junction to which it is attached in the immediate vicinity of the photoconductor. It will be noted that for each photoconductor **33***j* (say) on the device **21** there will be a corresponding semiconductor **34***j* on the device **22** at the same distance from the corresponding end of the P-N junction. Each of the pairs of corresponding photoconductors **33***a*, **34***a*, etc. is joined by a connecting wire **30***a*, **30***b*, **30***c*, etc. If the semiconductor device **21** is chosen to be the "input" device, a series of input lead wires **32***a*, **32***b*, **32***c*, etc. may be attached to each of the photoconductors **33***a*, **33***b*, **33***c*, etc. as shown. If a single input is desired to be introduced through all of the input lead wires, the lead wires all may be attached to an input terminal **31** as shown in FIGURE 3 of the drawings.

The semiconductor device **22** is therefore the "output" device, in association with which a series of output wires **35***a*, **35***b*, **35***c*, etc. may be provided, attached to corresponding photoconductors **34***a*, **34***b*, **34***c*, etc.

In operation, the end terminals **23** and **24** of the device **21** are oppositely poled relative to the end terminals **25** and **26** of the device **22**. In other words, if light is emitted from the right-hand side of the device **21**, light will be emitted from the left-hand side of the device **22**, and vice versa.

The current through the two devices **21** and **22** is as follows:

$$\epsilon I=\frac{E+\Delta}{R_0+(L-x)\rho}+\frac{E+\Delta}{R_0+(x)\rho}+$$

$$[E_1-(E+\Delta)]\sqrt{\frac{\sigma}{\rho}}[\coth\sqrt{\sigma\rho x}-\operatorname{cosech}\sqrt{\sigma\rho}x]+$$

$$[E_1{}^1-(E+\Delta)\sqrt{\frac{\rho}{\sigma}}[\coth\sqrt{\sigma\rho}(L-\quad)-\operatorname{cosech}\sqrt{\sigma\rho}(L-x)] \qquad (2)$$

where $E_1{}^1$ is the voltage required to cause a portion $(L-x)$ to conduct and all the other symbols are as defined in Equation 1

At intermediate positions, the light beams created by emission from the two semiconductor devices will overlap by a small amount; preferably only one pair of photoconductors will be overlapped by the light beams. As an example, in FIGURE 3, the light beam extending from the right-hand side of the semiconductor device **21** extends to the point **29**. The light beam extending from the left-hand side of the semiconductor device **22** extends as far as the point **69**. This means that the photoconductors **33***k* and **34***k* are the only corresponding pair of photoconductors which are excited by light. The photoconductor pair **33***j* and **34***j* will not be conductive because light does not reach the photoconductor **33***j*. Furthermore, the photoconductor pair **33***l* and **34***l* will not be conductive because light does not reach the photoconductor **34***l*. In other words, the only conducting circuit between the input terminal **31** and the series of output leads **35***a*, etc. is the circuit completed by the input wire **32***k* through the photoconductors **33***k* and **34***k* via connecting wire **30***k* and finally to the output wire **35***k*. It will readily be seen because of the non-conductivity of photoconductors **33***j* and **34***l* no conducting circuit is completed from terminal **31** through to output terminals **35***j* and **35***l*, or any other.

Only fifteen associated pairs of photoconductors are shown in the simplified diagram in FIGURE 3. In actual practice, perhaps hundreds of pairs would occupy the same few inches. The grid wires and photoconductor arrays may be manufactured by vapour deposition in conjunction with stencils or by photo-etching.

If the one-dimensional scanning device of FIGURE 3 is combined with another scanning device at right angles to it and the output photoconductors of each pair of scanning devices are provided with extending grid wires, a two-dimensional configuration of grid wires such as that shown in FIGURE 4 may be arranged. In this figure, the light-emitting semiconductor devices **38** and **39** are arranged in the same manner as the light-emitting semiconductor devices **21** and **22** shown in FIGURE 3. Each of the devices **38** and **39** is provided with regularly spaced corresponding photoconductors **55***a*, **55***b*, **55***c*, etc. and **54***a*, **54***b*, **54***c*, etc. to which a common input terminal **49** may be connected via input wires **53***a*, **53***b*, **53***c*, etc.

Similarly the semiconductor devices **36** and **37** are arranged side by side with corresponding photoconductors **51***a*, **51***b*, **51***c*, etc. and **52***a*, **52***b*, **52***c*, etc. spaced regularly thereon. Input wires **50***a*, **50***b*, **50***c*, etc., may be connected to the corresponding input photoconductors **51***a*, **51***b*, **51***c*, etc. and if a common input is desired a terminal **48** may be joined to each of the input lead wires **50***a*, **50***b*, etc. While only twelve, associated pairs of photoconductors are shown associated with each pair of junctions in the schematic diagram of FIGURE 4, several hundred or even thousand photoconductors may be placed on a junction in actual practice.

In FIGURE 4, as an exemplary operational point, the device **38** is shown as having a lighted section extending from the right-hand side to point **59** of the junction, and the device **39** is shown as having a lighted section extending as far as the point **60** from the left-hand side. This means that only the single pair of associated photoconductors **54***f* and **55***f* will have a complete circuit therethrough. Likewise, the junction **36** is shown as having a lighted section extending from the top of the device to the point **57** and the device **37** is shown as having a lighted section extending from the bottom up to the point **58**. Accordingly, only the corresponding pair of photoconductors **51***j* and **52***j* will form a complete circuit. Thus the point **56** is the only point on the entire grid display in which a conducting grid wire connected to the Y-input **48** overlaps with a conducting grid wire connected to the X-input **49**. This feature may be used to advantage in one of several ways.

For example, if the grid wires associated with the semiconductor pair **38** and **39** are spaced apart from the grid wires of the semiconductor pair **36** and **37** by a suitable electroluminescent layer, and A-C voltages are applied between terminals **48** and **49**, the configuration shown in FIGURE 4 may be used to give dynamic lighted displays in the same way as a cathode ray tube. By superimposing a few units with different phosphors, a colour display unit is obtained (i.e., various electroluminescent materials give different colours). FIGURE 5 illustrates the foregoing suggestion, in which an electroluminescent layer **61** is shown positioned between two sets of grid wires. A grid wire **53***p* is shown as extending vertically alongside the electroluminescent layer **61** while a series of grid wires **50***p*, **50***q*, **50***r* are shown as extending horizontally along the layer **61**. Thus, if the grid wire **53***p* and the grid wire **50***q* are the only ones conducting current, the only region of the electroluminescent layer **61** which will be subjected to appreciable excitation will be the region of intersection **62** of the two grid wires **53***p* and **50***q* shown enclosed approximately by broken lines in FIGURE 5. In all other regions of the electroluminescent layer insufficient or substantially no current flow will be present to cause light-emission from the electroluminescent layer. The excited region of the electroluminescent layer may be changed by changing the point of overlap of the light-emission of the junctions **38** and **39** or **36** and **37**. Thus the point of light emitted by the electroluminescent layer may be made to move in response to current variations in the P-N junctions. The intensity of the light is determined by the amplitude of the applied A-C voltage.

If the electroluminescent layer **61** is replaced by photoconductive layer then a camera-plate results. The grid wires, **50***p*, **50***q*, **50***r* and **53***p*, of the display unit configuration now function as outputs giving the resistance value of the photoconductive material between the grid wires selected by the scan. A video signal may then be obtained, in a well known manner, as the picture is scanned.

If the electroluminescent layer **61** is replaced by a potassium nitrate layer then a ferro-electric memory-plane results. Any spot at the intersection of two grid wires is able to store one "bit" of information because of the square loop nature of potassium nitrate. At the intersection, the grid wires effectively form a capacitor with the potassium nitrate as a dielectric and the spot may be selected by the scan, polarized or interrogated by voltage pulses which is analogous to magnetic core memory planes where current pulses are used to magnetize or interrogate. A three dimensional stack of memory planes may be used. A scanning device is used to select the plane desired by connecting the output wires of the scanning device to the input grid wires of the *x* or *y* scan of each plane. Word organized memorizes and associative memories can also be made.

If a circuit is connected to the grid wire **53***p* and to the grid wire **50***s*, an appropriate combinaton of pulses applied to terminals **48** and **49** (FIGURE 4) may be used to read information into or out of the memory element of layer **61**. Selection of the correct memory element is accomplished by choosing the correct point of overlap of light emission of the P-N junctions.

Instead of actuating an electroluminescent layer or one of a series of memory elements, selection of two overlapping grid wires may be used in switching circuits, for example of the cross-bar type used in the telephone arts.

For reasons of simplicity, the grid wires shown in FIGURE 5 have been illustrated as being bare wires. However, in actual practice, these wires are metal films made by vapor deposition techniques or photo-resist etching and are preferably embedded in sheets of plastic transparent plastic for visual displays such as those shown in FIGURE 7. Thus, a suitable sheet **61** of electroluminescent material or other material is sandwiched between two sheets **65** and **66** of plastic, which latter sheets bear the herizontal and vertical grid wires **50***p*, **50***q*, **50***r*, etc. and **53***p*, **53***q*, **53***r*, **53***s*, etc., respectively.

In referring to the devices of FIGURES 3 and 4 it has been suggested that the semiconductor devices are arranged so that a light-emitting overlay occurred between the two semiconductor junctions at all times, thereby connecting one and only one pair of corresponding photoconductors. This feature is difficult to achieve in practice because of the non-uniformity of the semiconductor devices resulting from non-uniformity in manufacture. In order to make possible near uniformity of the two associated junctions, the following manufacturing technique, discussed with reference to FIGURES 8 to 11 inclusive, is recommended. A plate **121** of intrinsic gallium-arsenide GaAs or gallium-arsenic phosphide $GaAs_xP_{(1-x)}$, where $0 \leq x \leq 1$ is masked on one side with a layer of silicon dioxide SiO_2, **122**, or other suitable material. An arsenic doped gold film is deposited on the other side **124**. Slits **125** and **126** are etched in the layer **122**. The slab is then baked in a zinc atmosphere at a temperature and for a duration to produce the desired properties as is well known in the art.

The result is as shown in FIGURE 11. Regions **127** and **128** are zinc doped p regions. It will be understood that these two regions extend along the length of the device but do not touch each other. Region **123** is an arsenic doped n region. This arsenic doping results from the diffusion of arsenic from the gold film **124** into the plate **121**.

At the junction of p and n regions there is a p-n junction. The diping level near the p-n junction is controlled by the previously mentioned baking temperature and duration control. It can in fact be an intrinsic region and hence a p-i-n junction. Thus, there can be a p-n junction equivalent to an ideal junction with a high series resistance to limit current and in particular, to prevent laser action.

Other manufacturing processes and geometries are possible and may be found to be superior. The above is intended to illustrate the requirements. It is necessary to provide some mechanism whereby errors caused by non-uniformity and non-linearity of the two associated semiconductor junctions used in the scanning device of FIGURE 3 may be eliminated. One hypothetical solution is that afforded by the scanning device shown in FIGURE 13. Instead of a pair of associated semiconductor junctions, the scanning device of FIGURE 13 employs a single scanning P-N junction. Along the length of the junction are disposed a series of photoconductors **107***p*, **107***q*, **107***r*, etc. Connected to these and displaced from the photoconductors by an appreciable amount are photoresistors **108***p*, **108***q*, **108***r*, etc. connected by grid wires **109***p*, **109***q*, **109***r* to the associated photoconductors. The photoconductors and photoresistors are shielded from external light and respond only to light emitted by the junction **105** in their immediate vicinity. The term "photoresistor" is here used in a special sense, namely, a device having the property of conducting readily in the dark but becoming a resistor of high resistance when exposed to light. In contrast, photoconductors do not conduct in the dark but conduct readily when exposed to light. The photoresistors **108***p*, **108***q*, **108***r* may be attached to convenient output grid wires **106***p*, **106***q*, **106***r*.

In operation, if light is emitted by the semiconductor junction **105** from the left-hand side as far as the line **150**, the photoconductor **107***q* will be in the light, whereas the photoresistor **108***q* will be in the dark. Therefore, a low resistance circuit is completed through both of the devices **107***q* and **108***q* connecting the input wire **111** to the output wire **106***q*. It will be noted that no circuit is completed between the input wire **111** and the output grid wires **106***p*, and **106***r*. This is because the photoresistor **108***p* is exposed to light and therefore does not conduct while the photoconductor **107***r* is not exposed to light and therefore does not conduct.

Photoresistors, commonly called "negative-photoconductors" are known in the art. For example, silver sulphide+1 to 2% lead sulphide (Ag_2S+1 to 2% PbS) is such a material. The known photoresistors are slow in response and therefore severely limit the scanning speeds. New materials may be found with greater speeds but until then an alternate solution is to use a scanning system such as that shown in FIGURE 14. In FIGURE 14, associated light-emitting P-N junctions **21** and **22** are provided with an input lead **31**, photoconductors **33***p*, **33***q*, **33***r*, **33***s*, etc. on the device **21** and **34***p*, **34***q*, **34***r*, **34***s*, etc. on the device **22**, connected by the wires **30***p*, **30***q*, **30***r*, **30***s*, etc. respectively. Additionally, output wires **35***p*, **35***q*, **35***r*, **35***s*, etc. are connected to the associated photoconductors **34***p*, **34***q*, **34***r*, **34***s*, etc. of the semiconductor device **22**. The device **22** corresponds exactly to that shown in FIGURE 3, except that each of the semiconductor devices **21** and **22** is additionally provided with sensing photoconductors **71***p*, **71***q*, **71***r*, **71***s*, etc. and **72***p*, **72***q*, **72***r*, **72***s*, etc. respectively. These are connected by corresponding connecting wires **73***p*, **73***q*, **73***r*, **73***s*. The sensing photoconductors **71***p*, **71***q*, **71***r*, **71***s*, etc. and **72***p*, **72***q*, **72***r*, **72***s* are also connected by corresponding connecting wires **74***p*, **74***q*, **74***r*, **74***s*, etc. and **76***p*, **76***q*, **76***r*, **76***s*, etc. to lead wires **75** and **77** respectively, which are connected to appropriate terminals **80** and **81** of an error feedback device **79**.

In operation, if light extends along the junction **21** so as to overlap with more than one pair of photoconductors in association with the junction **22**, the decrease in impedance at terminals **80** and **81** of the error feedback device **79** as a result of conduction through more than one pair of scanning photoconductors is such as to create correction voltages which may be applied via terminals **82** and/or **83** to the scanning signal lines, i.e. to the junction inputs (not shown). Conversely, if the light emitted by the device **22** fails to overlap with the light emitted by the device **21** so that no pair of photoconductors is conducting, the impedance at terminals **80** and **81** will increase and correction voltages of opposite polarity to the first-mentioned correction voltages are created by the error feedback device, and are applied to the junction input lines to cause current to increase in at least one of the semiconductor devices sufficiently so that light emitted by the devices **21** and **22** overlaps, causing one pair of associated photoconductors to conduct. It is preferable to eliminate one or the other of output terminals **82** and **83** and apply the correction voltage to only one of the P-N junctions, i.e., slaving one junction to another.

An embodiment of the error feedback device **79** illustrated in FIGURE 14 is further illustrated in the schematic block diagram of FIGURE 15 which employs standard control system notation.

The impedance of the composite parallel-series network of photoconductors terminating at terminals **80** and **81** is represented by a single sensing resistor **130** in FIGURE 15. This resistor **130** is connected in series with a fixed resistor **131** of predetermined value across a balanced source of potential. The junction of the two resistors, reference point **132**, is connected to the input of a first Schmitt trigger circuit **133** which is responsive to positive signals voltages and a second Schmitt trigger circuit **134** which is responsive to negative signal voltages. The output of the first and second trigger circuits **133** and **134** is connected through first and second Zener diodes **135** and **136** respectively to a balanced adder network comprising a pair of serially connected resistors **137** and **138** connected in shunt with a pair of serially connected capacitors **139** and **140**.

If at a particular instant the illuminated portions of the devices **21** and **22** do not overlap then no pair of associated photoconductors will conduct. Consequently, the impedance at terminals **80** and **81** and hence the impedance of the sensing resistor **130** illustrated in FIGURE 15 will be relatively high. This results in a positive voltage appearing at reference point **132** which in turn causes the Schmitt trigger circuit **133** to conduct. The output voltage of the trigger circuit is then sufficient to cause Zener diode **135** to conduct which results in a positive signal voltage increase appearing at the junction of the two serially connected resistors **137** and **138**. This signal voltage is coupled to the input terminals of a D-C amplifier **141**.

By design, when one pair of photoconductors is conducting the impedance of the sensing resistor **130** equals the impedance of the fixed resistor **131**. The voltage at the reference point **132** is therefore zero. Hence, neither Schmitt trigger circuit **133** or **134** conducts and the voltage applied to the amplifier **141** remains approximately constant due to the time constant of the resistor-capacitor combination comprising components **137, 138, 139** and **140**.

When two or more pairs of photoconductors are conducting the impedance of the sensing resistor **130** will be substantially less than the impedance of the fixed resistor **131**. This results in a negative voltage appearing at the reference point **132** which in turn results in a negative voltage change being applied to the amplifier **141**.

A scanning signal voltage for the two light-emitting junctions **21** and **22** is supplied by a conventional scanning signal generator **142**. The output from the generator **142** is coupled through a divider network **143** directly to the light-emitting junction **21** and indirectly through an adder network **144** to the light-emitting junction **22**.

The D-C output from the amplifier **141** is also coupled to the adder network **144**. Thus, when two or more pairs of associated photoconductors are conducting, the output from the D-C amplifier is such that it opposes the scanning voltage being applied to the light-emitting junction **22** and thereby diminishes the illuminated portion of the junction until only one pair of associated photoconductors are conducting. Conversely, when none of the pairs of photoconductors are conducting, the output voltage from the amplifier **141** is such that it aids the scanning voltage until one pair of photoconductors is conducting. Of course, when the two light-emitting sources are in step, neither of the Schmitt trigger circuits **133** or **134** are triggered and consequently no variation in the output of the amplifier **141** results.

The following theory in conjunction with FIGURE 12 shows the development of the formulae given above.

The circuit shown in FIGURE 12 is a discrete equivalent of a long narrow P-N junction of the configuration shown in FIGURE 1. Here, the series impedance of the device between the terminals **14** and **15** is represented by the lumped resistances **85***a*, **85***b*, **85***c*, **85***d* and **85***e*; the junction itself is represented by the photo-emissive diodes **86***a*, **86***b*, **86***c* and **86***d*; and the forward conductance of the junction by the shunt resistors **87***a*, **87***b*, **87***c* and **87***d*. As the number of sections N approaches infinity then

$$R' \rightarrow \infty$$

such that

$$\frac{N}{R'} = \text{constant } K_1$$

$$R \rightarrow 0$$

such that

$$R \times N = \text{constant } K_2$$

The discrete circuit FIGURE 12 will then have typical properties of the long narrow P-N junction shown in FIGURE 1. If the normal diode equation is used the equations for the circuit are difficult to solve. However, if R' is sufficiently large (i.e. K_1 is small) then the nonlinear terms can be neglected and the diodes can be regarded as having infinite back resistance and zero forward resistance.

The problem is approached by solving the simple configuration shown in FIGURE 1. For this, it is assumed that the junction of the layers is ohmic (i.e. that is purely resistive).

$$I(x) = I_1 - \int_0^x \sigma[V(x) - E]dx \tag{3}$$

$$V(x) - E_1 - \int_0^x \rho I(x)dx \tag{4}$$

The equations are then solved for the general solution:

$$I(x) = -\sqrt{\frac{\sigma}{\rho}}\left[C_1 e^{\sqrt{\sigma\rho}x} - C_2 e^{-\sqrt{\sigma\rho}x}\right] \tag{5}$$

$$V(x) = C_1 e^{\sqrt{\sigma\rho}x} + C_2 e^{-\sqrt{\sigma\rho}x} + E \tag{6}$$

The boundary conditions are:

$$V_O = E_1$$

$$V_L = E_2$$

hence

$$C_1 + C_2 = E_1 - E$$

and

$$e^{\sqrt{\sigma\rho}L} C_1 + e^{-\sqrt{\sigma\rho}L} = E_2 - E$$

The equations are then solved for C_1 and C_2

$$C_1 = \frac{\left[(E_1 - E)e^{-\sqrt{\sigma\rho}L} - (E_2 - E)\right]}{e^{-\sqrt{\sigma\rho}L} - e^{\sqrt{\sigma\rho}L}} \tag{7}$$

$$C_2 = \frac{\left[(E_2 - E) - (E_1 - E)e^{\sqrt{\sigma\rho}L}\right]}{e^{-\sqrt{\sigma\rho}L} - e^{\sqrt{\sigma\rho}L}} \tag{8}$$

and

$$I_1 \sqrt{\frac{\sigma}{\rho}}(C_2 - C_1) \tag{9}$$

$$I_2 \sqrt{\frac{\sigma}{\rho}}\left(C_2 e^{\sqrt{\sigma\rho}L} - C_1 e^{\sqrt{\sigma\rho}L}\right) \tag{10}$$

Consider now FIGURE 2 with terminal **18** grounded.

$$I_2 R = E_2$$

From Equations 9 and 10

$$\frac{E_2}{R} = \sqrt{\frac{\sigma}{\rho}}\left(C_2 e^{-\sqrt{\sigma\rho}L} - C_1 e^{\sqrt{\sigma\rho}L}\right) \tag{11}$$

substitution of C_2 and C_1 from Equations 7 and 8 and solving for E_2 yields:

$$E_2 = \frac{E \coth \sqrt{\sigma\rho}L + (E_1 - E) \operatorname{cosech} \sqrt{\sigma\rho}L}{\coth \sqrt{\sigma\rho}L + \sqrt{\frac{\sigma}{\rho}}/R} \tag{12}$$

In FIGURE 6 section *x* of the junction is forward biased and the rest of the junction is reverse biased. Hence, we can regard the forward biased section as the configuration in FIGURE 2 and the reverse biased section as a resistor R' where:

$$R' = (L - x)\rho$$

since no current flows across the $(L - x)$ portion of the junction. Hence, effectively we have the situation as in FIGURE 2 and Equation 12 describes this case with

$$R = (R' + R_0) \text{ or } [R_0 + (L - x)\rho],$$
$$E_2 = E$$

a term Δ added to E to account for barrier potential of the p-n junction.

Thus:

$$E+\Delta=\frac{E+\Delta\coth\sqrt{\sigma\rho}x+[E_1-(E+\Delta)]\operatorname{cosech}\sqrt{\sigma\rho}x}{\coth\sqrt{\sigma\rho}x+\sqrt{\frac{\rho}{\sigma}}/\rho(L-x)+R_0}\tag{13}$$

simplifying Equation 13

$$E_1=(E+\Delta)\left[\frac{\sqrt{\frac{\rho}{\sigma}}\sinh\sqrt{\sigma\rho}x}{\rho(L-x)+R_0}+1\right]\tag{14}$$

valid for

$$L\geq X\geq 0$$

where:

E_1=voltage at terminal **15**
E_2=voltage at terminal **14**
E=voltage at terminal **16**
Δ=barrier voltage of the p-n junction
R_0=terminating resistor from terminal **14** to ground
ρ=resistance per unit length of layer **11**
σ=conductance per unit length of layer **12**
coth=hyperbolic cotangent
cosech=hyperbolic cosecant
sinh=hyperbolic sine

In Equation 14 if x and E are specified then the required voltage E_1 at terminal **15** can be found.

Referring to FIGURE 12 it is obvious that a deposited array of discrete light emitting diodes and resistors will also serve in applications where long narrow light emitting p-n junctions are used with photo-diodes or phototransistors replacing the photo-conductive material.

The relationship between I_1 and x is as follows in FIGURE 2:

$$I_1=\frac{E+\Delta}{R_0+(L-x)\rho}+\int_0^{x}[E(\xi)-(E+\Delta)]\sigma d\xi\tag{15}$$

but

$$E(\xi)=C_1e^{\sqrt{\sigma\rho}\xi}+C_2e^{-\sqrt{\sigma\rho}\xi}+(E+\Delta)$$

where

$$C_1=\frac{e^{-\sqrt{\sigma\rho}x}[E_1-(E+\Delta)]}{e^{-\sqrt{\sigma\rho}x}-e^{\sqrt{\sigma\rho}x}}$$

$$C_2=\frac{-[E_1-(E+\Delta)e^{\sqrt{\sigma\rho}x}}{e^{-\sqrt{\sigma\rho}x}-e^{\sqrt{\sigma\rho}x}}\tag{16}$$

therefore

$$E(\xi)=\frac{\left[e^{\sqrt{\sigma\rho}(\xi-x)}-e^{-\sqrt{\sigma\rho}(\xi-x)}\right][E_1-(E+\Delta)]}{e^{-\sqrt{\sigma\rho}x}-e^{\sqrt{\sigma\rho}x}}+(E+\Delta)\tag{17}$$

therefore

$$\frac{I_1=E+\Delta}{R_0+(L+X)\rho}+\int_0^{x}\frac{\left[e^{\sqrt{\sigma\rho}(\xi-x)}-e^{-\sqrt{\sigma\rho}(\xi-x)}\right]}{\left[e^{-\sqrt{\sigma\rho}x}-e^{\sqrt{\sigma\rho}x}\right]}\cdot[E_1-(E+\Delta)]\sigma d\xi\tag{18}$$

$$I_1=\frac{E+\Delta}{R_0+(L-X)\rho}+[E_1-(E+\Delta)]\sqrt{\frac{\sigma}{\rho}}[\coth\sqrt{\rho\sigma}x-\operatorname{cosech}\sqrt{\rho\sigma}x\tag{19}$$

where:

$I_1=I_2+$the current through the junction
$E(\xi)$=voltage along the forward biased portion
ξ=a dummy variable

and all the others terms are as previously defined.

A discrete equivalent of the long-narrow P-N junction illustrated in FIGURE 12 can be substituted for the light-emitting junctions **21** and **22** illustrated in FIGURE 14. This is shown in FIGURE 16 in which device **21** is replaced by series lump resistances **200***a*, **200***b*, **200***c*, **200***d* and **200***e*, diodes **201***a*, **201***b*, **201***c* and **201***d*, and shunt resistors **202***a*, **202***b*, **202***c* and **202***d*; and device **22** is replaced by series lump resistances **203***a*, **203***b*, **203***c*, **203***d* and **203***e*, diodes **204***a*, **204***b*, **204***c*, **204***d*, and shunt resistors **205***a*, **205***b*, **205***c* and **205***d*. These components perform the same function as their equivalents hereinbefore described with reference to FIGURE 12. In juxtaposition with diodes **201***a*–**201***d* and **204***a*–**204***d* are photoconductors **33***p*–**33***s* and **34***s*–**34***p* respectively. Also in juxtaposition with the diodes **201***a*–**201***d* and **204***a*–**204***d* are sensing photoconductors **71***p*–**71***s* and **72***s*–**72***p* respectively. The input lead **31**, the connecting wire **30***p*–**30***s* and the output wires **35***p*–**35***s* are connected in an identical manner to that shown in FIGURE 14. Also, connecting wires **73***p*–**73***s*, **74***p*–**74***s*, **76***p*–**76***s* and lead wires **75** and **77** are connected in an identical manner to the components and to the terminals **80** and **81** of the error feedback device **79** as those illustrated in FIGURE 14.

The operation of the device illustrated in FIGURE 16 is basically identical to that illustrated in FIGURE 14. With appropriate voltages connected to terminals **206**, **207**, and **208**, **209**, **210** and **211**, which are equivalent to terminals **14**, **15** and **16** in FIGURE 12, light will be emitted, commencing at opposite ends, from diodes **201***a*–**201***d* and **204***a*–**204***d*. If more than one pair of overlapping diodes or no pair of overlapping diodes is conducting, an error feedback voltage will be fed to terminals **80** and **81** and will thereby apply appropriate correction voltages, as hereinbefore described with reference to FIGURE 15, until only one pair of diodes is conducting.

The linear-resolution of the semiconductor device **10** is dependent on the width of the transition zone of light emission from the junction. This zone is defined as being from the threshold value of light emission to the saturation illumination of the photoconductors used. The width of the transition zone is dependent on the voltage gradient along the long narrow junction, as is evident from the previous developed equations. In deriving the equations simplifying assumptions were made. For example carrier-modulation by the injection of minority carriers into the upper layer was not considered. This carrier-modulation tends to lower ρ (the resistance per unit length of the upper layer), in the forward biased section of the long narrow junction. Hence, the longitudinal voltage-gradient at the transition zone is increased and the zone is narrowed, therefore improving the resolution. To narrow the transition zone and at the same time limit the current in the forward-biased section of the long narrow junction, a structure having a constant current characteristic (similar to the characteristics of a pentode vacuum tube) for individual points along the junction, may be incorporated in the junction. The above described long-narrow junction and its various modifications can be conventionally represented in discreet-equivalent circuits. The equivalent circuits may be translated into actual circuits in the form of discreet-components or integrated-circuit forms. Examples of such structures are a field-effect transistor, an insulated gate transistor, and high-field triode types described hereinafter.

FIGURES 17 and 18 illustrate a field-effect structure of a long narrow light-emitting device generally indicated by the numeral **220**. The device **220** comprises the lower semiconductor layer **12**, which may for example be N-doped, in p-n contact with the upper semiconductor layer **11**, which may for example be P-doped, and the conducting base layer **13** which is preferably made of metal. Terminals **14** and **15** are attached to the upper semiconductor layer **11** while terminal **16** is connected to the conductive layer **13**. An additional semiconductor layer **221** overlays a portion of the length of the lower semiconductor layer **12**. Coextensive with the layer **221** and in ohmic contact with it is a conductive layer **222**. A terminal **223** is attached to the conductive layer **222**. With appropriate voltages connected to terminals **14**, **15** and **16** as hereinbefore described with reference to FIGURE 2, light emission occurs near the junction of the layers **11** and **12** in the forward biased region. The improvement over the simple long narrow junction illustrated in FIGURES 1 and 2 comprises the additional semiconductor layer **221**, which in the present example would be P-doped. In operation, terminal **223** is maintained at a constant voltage relative to terminal **16**. The terminal **222** may be connected to the terminal **16**. The semiconductor layers **12** and **221** form the field effect structure which provides a constant-current characteristic, similar to that of a pentode vacuum tube, at each point along the junction between the layers **11** and **12**.

FIGURES 19 and 20 illustrate an insulated-gate structure of a long narrow light-emitting device generally indicated by the numeral **230**. The device comprises semiconductor layers **11** and **12** and terminals **14** and **15** all disposed in a manner similar to that hereinbefore described with reference to FIGURES 1 and 2. However, interposed between the semiconductor layer **12** and the conducting base layer **13** are a semiconductor layer **231**, which in the present example would be P-doped, and a semiconductor layer **232**, which in the present example would be N-doped. Semiconductor layers **231** and **232** are in p-n contact with each other while semiconductor layer **231** is in p-n contact with semiconductor layer **12** and semiconductor layer **232** is in ohmic contact with the conductive base layer **13**.

A dielectric layer **233** overlays semiconductor layers **12**, **231** and **232**. The layer **233** may be made of silicon monoxide or dioxide. Coextensive with the layer **233** and in contact with it, is a conductive layer **234**. Attached to the conductive layer **234** is terminal **235**. As hereinbefore described with reference to FIGURES 1 and 2, light is emitted near the forward biased region of the junction between layers **11** and **12**. In operation, the terminal **235** is maintained at a constant voltage relative to the terminal **16**. The layers **231**, **232**, **233** and **234** in conjunction with a portion of layer **12** form the well-known insulated gate (transistor) structure. The desired constant current characteristics at each point along the junction between the layers **11** and **12** result from this structure.

FIGURES 21 and 22 illustrate a high-field triode structure of a long narrow light-emitting junction generally indicated by numeral **240**. Semiconductor layers **11** and **12** in conjunction with terminals **14** and **15** function as hereinbefore described with reference to FIGURES 1 and 2. Interposed between the layer **12** and the conductive layer **13** and in p-n contact with them is a heavily doped semiconductor layer **241** which in the present example is P+ type. A thin dielectric layer, which may for example be made of silicon dioxide, in the order of 1000 angstroms thick, is placed over portions of the layers **12** and **241**. A conductive layer **243** is placed over the dielectric layer **242** and is coextensive with it and with the length of the device **240**. A terminal **244** is attached to the conductive layer **243**. Light emission occurs near the junction of the layers **11** and **12** and in the forward biased region as hereinbefore described with reference to FIGURES 1 and 2. The addition of the heavily doped semiconductor layer **241**, the dielectric layer **242** and the conductive layer **243** over the dielectric layer **242** provide the constant current characteristics of the device **240**. In operation, the terminal **244** is maintained at a constant voltage relative to the terminal **16**.

The structures described with reference to FIGURES 17–22 illustrate examples of the present invention having a constant-current characteristic for individual stages along the junction. The figures are not drawn to scale, the height and width of the various semiconductor layers being exaggerated for clarity. It will be understood that it is not necessary to use the exact geometry shown in the various embodiments, provided that, the topology of the geometry is maintained and the geometry adjusted according to the requirements of the fabrication processes used. In addition, the conductivity of the semiconductor layers may be reversed; that is a P-type layer may be replaced by an N-type layer and also the converse relationship.

The use of field-effect transistors, insulated-gate transistors, and high-field triodes as current-limiting devices is well known. In the present invention the current-limiting aspect of these devices is incorporated over a large region coextensive with the plane of the junction of the semiconductor layers **11** and **12**. This improvement over the simple long-narrow junction of the voltage-scanned device **10** helps to improve the resolution and to limit the current in the forward biased section of the junction, thereby reducing the required scan-drive power and the dissipation.

The embodiments described above incorporating the field-effect structure, the insulated gate structure and the high-field triode structure as current limiting devices, may be represented by a discreet equivalent circuit illustrated in FIGURE 23. The device is similar to that shown in FIGURE 12 in which the series impedance between the terminals **14** and **15** is represented by the lump resistances **85*a***, **85*b***, **85*c***, **85*d***, and **85*e***; and the junction is represented by the photo-emissive diodes **85*a***, **85*b***, **85*c***, and **85*d***. However, the forward conductance of the device (which was shown in FIGURE 12 as shunt resistors **87*a***, **87*b***, **87*c*** and **87*d***) is now represented by non-linear resistances **89*a***, **9*b***, **89*c***, and **89*d***. The function of the non-linear resistances **89*a*–89*d***, which display a constant-current characteristic, similar to that of a pentode vacuum tube, is to limit the current through the diodes **86*a*–86*d***. This maintains the diode light emission constant and also acts as a safety measure to avoid overloading the diodes **86*a*–86*d***. Diodes **88*a***,**88*b***, **88*c*** and **88*d*** are added to protect the light-emitting diodes **86*a*–86*d*** from excessive back voltage. The equivalent circuit illustrated in FIGURE 23 is therefore another form of the discrete equivalent of a long narrow light-emitting junction illustrated in FIGURE 12.

What I claim as my invention is:

1. A voltage-indicating or current-indicating device comprising a conducting layer, a semiconductor layer in close contact with the conducting layer, and a second semiconductor layer of opposite conductivity to the first semiconductor layer and in close contact with the first semiconductor layer, all layers being of equal length and of uniform cross section, a pair of terminals one at either end of the second semiconductor layer, and a terminal attached to the conducting layer, the said semiconductor layers being selected so that current flow through the junction between said layers causes emission of light.

2. A device as defined in claim **1**, wherein the conducting layer is metal.

3. A device as defined in claim **2**, wherein the said semiconductor layers are formed in a crystal of n-type gallium arsenide, and the p-type semiconductor layer is formed by doping said crystal with zinc.

4. A device as defined in claim **2** wherein the semiconductor layers are formed in a crystal of n-type gallium arsenide$_x$phosphide$_{(1-x)}$, (where $0<x<1$), and the p-type semiconductor layer is formed by doping said crystal with zinc.

5. A scanning device comprising a first long, narrow light-emitting P-N junction the length of whose light-emitting portion can be varied electrically and of the same overall length as said first junction, a plurality of regularly spaced photoconductors mounted correspondingly on each of said P-N junction devices, a plurality of lead lines each connected to a discrete one of the photoconductors on the first P-N junction device, a plurality of connecting wires connecting each of the photoconductors on the first P-N junction device to the corresponding photoconductor on the second P-N junction device, and a plurality of output lines each emanating from a discrete one of the photoconductors on said second P-N junction device.

6. A two-dimensional scanning apparatus comprising a first pair of equally long, narrow light-emitting P-N junction devices the lengths of whose light-emitting portions can be varied electrically and each emitting light as a result of current flow through the P-N junction, the light emanating from opposite ends of the devices, the total light emission through both P-N junction devices being constant, the P-N junctions bearing regularly and correspondingly spaced photoconductors, the photoconductors being correspondingly interconnected, the photoconductors on one of said devices being connected to an input line the photoconductors on the other of said devices being connected to a first series of parallel grid wires, a second pair of equally long, narrow P-N junction devices the lengths of whose light-emitting portions can be varied electrically and bearing a plurality of regularly and correspondingly spaced photoconductors correspondingly interconnected, the photoconductors on one of said second pair of devices being connected to an input line, the photoconductors on the other of said second pair of devices being connected to a second series of parallel grid wires at right angles to said first series of parallel grid wires.

7. A device as defined in claim 5, additionally including a plane electroluminescent layer interposed between and in contact with the first series of grid wires and the second series of grid wires.

8. A device as defined in claim 5, additionally including an array of information storage devices each arranged to contact a discrete one of said first series of grid wires and a discrete one of said second series of grid wires.

9. A scanning device comprising a first and a second long, narrow light-emitting P-N junction the length of whose light-emitting portion can be varied electrically, each junction bearing correspondingly and regularly spaced photoconductors which conduct in response to light emission from an adjacent portion of the junction, the corresponding photoconductors on the two P-N junctions being interconnected by a plurality of connecting wires, an input line connected to each of the photoconductors on the first P-N junction by a plurality of lead wires, a plurality of output lines, one leading from each of the photoconductors on the second P-N junction device, a source of scanning current applied to opposite ends of the P-N junctions, the current being controllably divided between the two junctions and the total current applied to both devices maintaining constant total light emission from the junctions and sufficient to cause the light emission from the junctions to excite one pair of corresponding photoconductors, a first and a second series of sensing photoconductors, one series for each P-N junction, said sensing photoconductors being spaced equally with and adjacent to said first-mentioned photoconductors, interconnecting lines between corresponding sensing photoconductors on the first and second P-N junctions, an error feedback device having an input and an output, the input being connected to the first and second series of sensing photoconductors, the error feedback device producing at its output a correction voltage related to the signals received from the first and second series of sensing photoconductors, the output being connected to at least one of said light-emitting P-N junctions, the correction voltage causing one and only one pair of corresponding first-mentioned photoconductors to conduct.

10. A scanning device comprising a long, narrow light-emitting P-N junction the length of whose light-emitting portion can be varied electrically, a plurality of photoconductors responsive to light emitted by an adjacent portion of the junction and regularly spaced along said P-N junction, a plurality of photoresistors responsive to light emitted from an adjacent portion of said junction and regularly spaced at equal intervals with the photoconductors along said P-N junction but displaced from each corresponding photoconductor along the length of the P-N junction, interconnecting means between each photoresistor and its corresponding photoconductor, an input line connected to each of said photoresistors and an output line connected to each of said photoconductors.

11. In a scanning device for selecting one of a series of electrical elements in response to an input scanning signal, the improvement comprising a first light-emitting semiconductor junction the length of whose light-emitting portion can be varied electrically having regularly spaced along its length a first series of photoconductors, a second light-emitting semiconductor junction the length of whose light-emitting portion can be varied electrically of substantially the same dimensions as the first junction and having spaced along its length a second series of photoconductors each connected to one of said series of electrical elements and spaced apart by the same distance as said first series of photoconductors and in one-to-one correspondence with said first series of photoconductors, each of said photoconductors being responsive only to light emitted in its immediate vicinity by its associated junction, means to apply said scanning signal to the two junctions, input means connected to each of the first series of photoconductors wherein light is emitted from non-corresponding ends of the two junctions in response to the scanning signal input, variation in the scanning signal causing variation in the length of the light-emitting portion of each junction, the sum of the lengths of the light-emitting portions of the two junctions being slightly greater than the length of one junction thereby to cause one and only one corresponding pair of photoconductors to be excited by light emitted by the junctions.

12. A device as defined in claim 11, additionally including sensing means associated with each pair of corresponding photoconductors and providing a signal when the associated pair of corresponding photoconductors is excited by light emitted by the junction, an error signal generator responsive to the signals produced by the sensing means and generating an output signal which is fed to at least one of the junctions and which decreases the length of the light-emitting portion of said last-mentioned junction if more than one corresponding pair of photoconductors is excited by light and which increases the length of the light-emitting portions of said last-mentioned junction if no corresponding pair of photoconductors is excited by light.

13. The combination of two scanning devices as defined in claim 11, wherein the series of electrical elements to which each of the scanning devices is connected is extended as a series of parallel grid wires spaced apart from and at an angle to the parallel grid wires connected to the other scanning device, and additionally including electroresponsive means disposed between the two series of grid wires and connecting the grid wires of one series to the grid wires of the other series at the points of crossover of the grid wires.

14. The combination defined in claim 13, wherein the electroresponsive means is an electroluminescent layer sandwiched between the two series of grid wires.

15. The combination defined in claim 13, wherein the electroresponsive means is a photoconductive layer sandwiched between the two series of grid wires.

16. The combination defined in claim 13, wherein the electroresponsive means is a plurality of information storage devices each connected between a unique pair of grid wires, one from each series, at the point of crossover of said last-mentioned wires.

17. In a scanning device, the improvement comprising a long-narrow light-emitting semiconductor junction, the length of the light-emitting portion of the junction being variable, a series of photoconductors regularly spaced along the length of the junction, a series of light-responsive devices spaced along the length of the junction in one-to-one correspondence with the series of photoconductors, each light-responsive device being connected to and dis-

placed from its corresponding photoconductor by a constant distance less than the spacing between adjacent photoconductors, each light-responsive device being conductive in the dark and resistive in the light, each photoconductor and each light-responsive device being responsive only to light in its respective immediate vicinity emitted by the junction.

18. A voltage-indicating or current-indicating device comprising a plurality of resistors connected in series between a first and second terminal, and a separate photo-emissive diode and a resistor connected in series between each junction of said plurality of resistors and a common third terminal, each of said photo-emissive diodes having the same polarity with respect to said third terminal.

19. A scanning device comprising a first photo-emissive device having a plurality of resistors connected in series between a first and a second terminal, a separate photo-emissive diode and a resistor connected in series between each junction of said plurality of resistors and a common third terminal, each of said photo-emissive diodes having the same polarity with respect to said third terminal; a second photo-emissive device having a plurality of resistors connected in series between a fourth and a fifth terminal, a separate photo-emissive diode and a resistor connected in series between each junction of said plurality of resistors and a common sixth terminal, each of said photo-emissive diodes having the same polarity with respect to said sixth terminal; in juxtaposition with each of said photo-emissive diodes a photoconductor which conducts in response to light emission from the adjacent photo-emissive diode, the corresponding photoconductors of the two photo-emissive devices being interconnected by a plurality of connecting wires; an input line connected to each of the photoconductors adjacent the first device by a plurality of lead wires; a plurality of output lines, one leading from each of the photoconductors adjacent the second device; a source of scanning current applied to opposite end terminals of the first and second devices, the current being controllably divided between the two devices and the total current applied to both devices maintaining constant total light emission from the two devices and sufficient to cause the light emission from the devices to excite one pair of corresponding photoconductors; in juxtaposition with each of said photo-emissive diodes a plurality of sensing photoconductors, interconnecting lines between corresponding sensing photoconductors adjacent the first and the second devices; an error feedback device having an input and an output, the input being connected to the first and second series of sensing photo-conductors, the error feedback device producing at its output a correction voltage related to the signals received from the first and second series of photoconductors, the output being connected to at least one of said devices, and the correction voltage causing one and only one pair of corresponding photoconductors to conduct.

20. A voltage-indicating or current-indicating device as defined in claim **1** further comprising means for limiting the maximum flow of current at each stage along the forward biased section of said junction.

21. A device as defined in claim **1** further comprising a third semiconductor layer in p-n contact with and coextensive with the length of said first semiconductor layer, said third semiconductor layer being of the same conductivity as the second semiconductor layer; a further conducting layer in ohmic contact with and coextensive with the length of said third semiconductor layer, and a further terminal attached to said further conducting layer.

22. A device as defined in claim **1** further comprising a third and a fourth semiconductor layer of the same conductivity as said second and first semiconductor layer respectively, said third and fourth semiconductor layers being coextensive with and interposed said first semiconductor layer and said conducting layer so that the third semiconductor layer is in p-n contact with the first and fourth semiconductor layers and the fourth semiconductor layer is in ohmic contact with the conducting layer, a dielectric layer coextensive with and overlaying the length of said first, third and fourth semiconductor layers, a further conducting layer overlaying the length of said dielectric layer and a further terminal attached to said further conducting layer.

23. A voltage-indicating or current-indicating device as defined in claim **1** further comprising a heavily doped semiconductor layer, of the same conductivity as the second semiconductor layer, interposed and coextensive with the length of said first semiconductor layer and said conducting layer, a dielectric layer coextensive with and overlaying the length of said first and said heavily doped semiconductor layers, a further conducting layer overlaying the length of said dielectric layer and a further terminal attached to said further conducting layer.

24. A voltage-indicating or current-indicating device comprising a plurality of resistors connected in series between a first and a second terminal, and a separate photo-emissive diode, further diode and a non-linear resistance connected in series between each junction of said plurality of resistors and a common third terminal, each of said photo-emissive diodes and said further diodes having the same polarity with respect to said third terminal.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,388,255 June 11, 1968

George A. May

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading to the printed specification, lines 6 and 7, "3621 Ayemer St., Apt. 3, London, Ontario, Canada" should read -- 2301 Agronomy Place, Vancouver 8, British Columbia, Canada --. Column 15, lines 26 and 30, the claim reference numeral "5", each occurrence, should read -- 6 --.

Signed and sealed this 13th day of January 1970.

(SEAL)

Attest:

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Commissioner of Patents