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[54] DOUBLE INJECTION DIODE MATRIX SWITCH
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[51] Int. Cl. H01j 39/12
[50] Field of Search 340/166,
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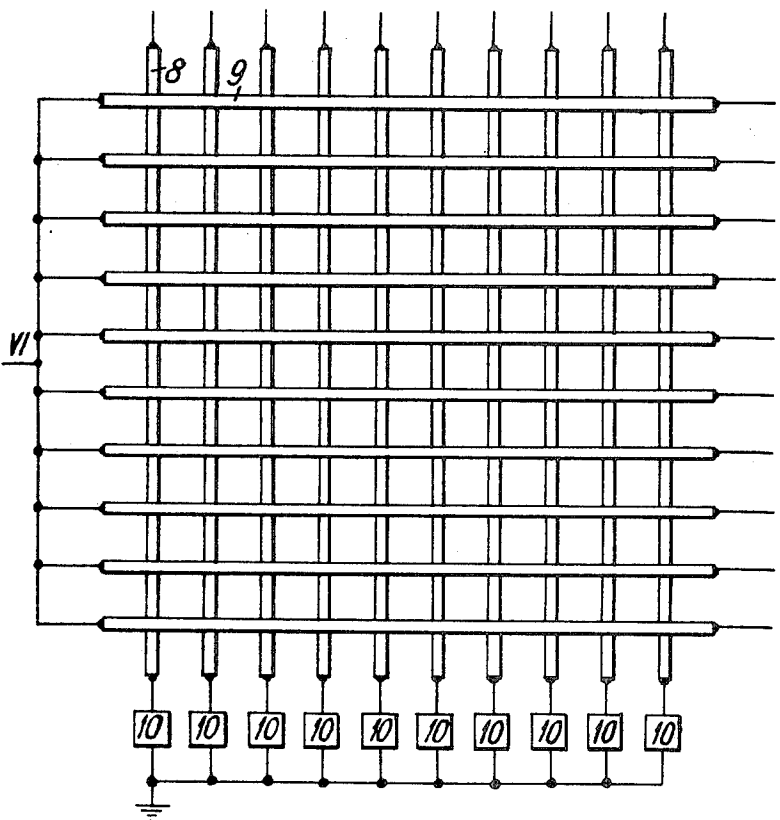
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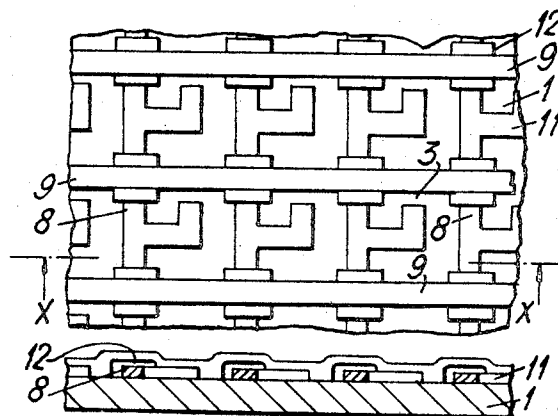
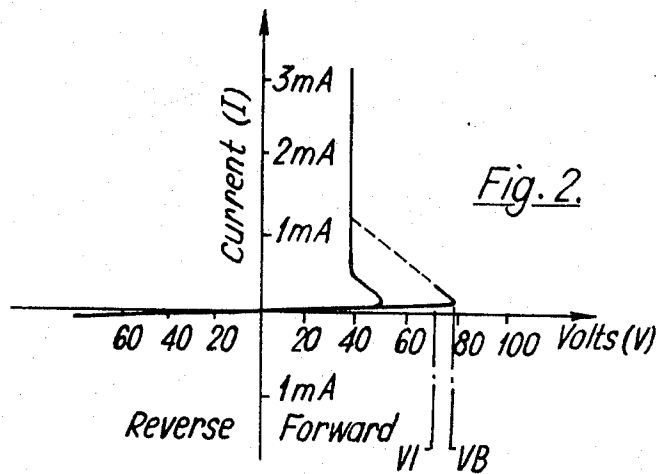
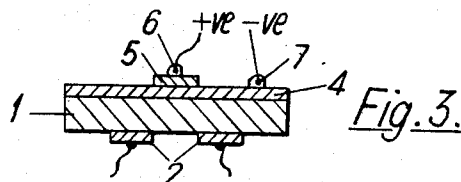
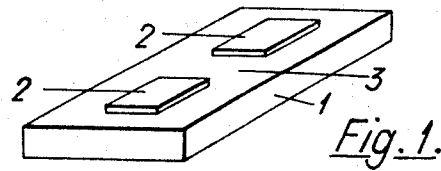
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ABSTRACT: A cross-point switch utilizing opto-electronic switches at the cross-points. The switches can be a plurality of double-injection diodes formed from a common body of semiconductive material. Various constructions and materials are used for the cross-point switches. A number of ways of illuminating the individual diodes discretely are shown together with different ways of switching the light from one diode to another.





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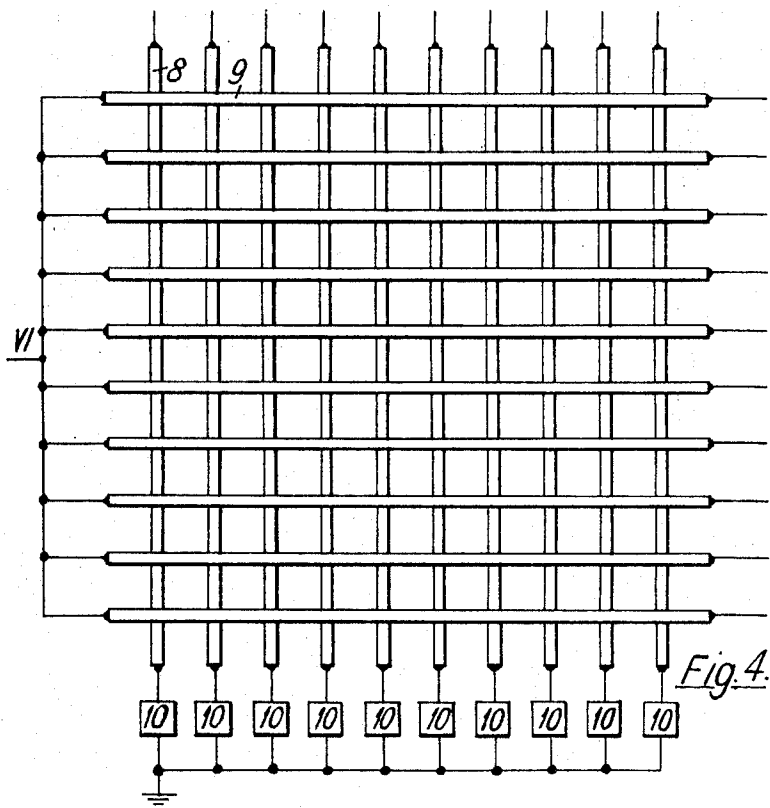


Fig. 4.

Fig. 6A

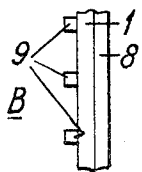
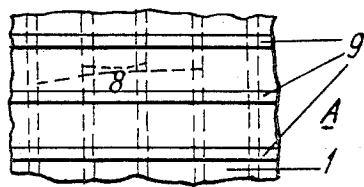


Fig. 6B

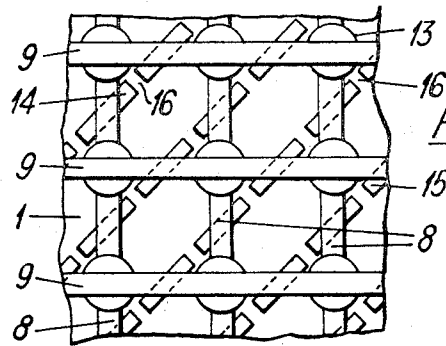


Fig. 7.

DOUBLE INJECTION DIODE MATRIX SWITCH

The invention relates to cross-point switches which utilize double injection diodes as opto-electronic switches and to methods of manufacturing the switches.

The invention provides a cross-point point including a plurality of double injection diodes arranged in rows and columns, wherein said plurality of double injection diodes which are normally biased to a voltage level less than the voltage required to switch said double injection diodes from their normally low conduction state to a high conduction state can be switched into said high conduction state by the application of suitable incident light.

The invention also provides a method of manufacturing a cross-point switch which includes the steps of depositing a first plurality of metal strips onto one face of a body of semiconductive material, said first plurality of metal strips being equally spaced and parallel to each other, depositing at regular intervals along each of said first plurality of metal strips regions of insulating material, depositing a second plurality of metal strips onto said one face of said body of semiconductive material substantially at right angles to said first plurality of metal strips, said second plurality of metal strips being spaced so as to overlap said regions of insulating material and providing means for forming a diode gap at each of the crossover point of said first and second pluralities of strips.

The invention further provides a method of manufacturing a cross-point switch which includes the steps of depositing a first plurality of metal strips onto one face of a body of semiconductive material, said first plurality of metal strips being equally spaced and parallel to each other, depositing a second plurality of metal strips on the face of said body of semiconductive material which is opposite said first plurality of metal strips, said second plurality of metal strips which are equally spaced and parallel to each other are substantially at right angles to said first plurality of metal strips, wherein a diode gap is provided between said first and second pluralities of metal strips at each of the crossover points of said first and second pluralities of strips.

The foregoing and other features according to the invention will be understood from the following description with reference to the accompanying drawings, in which:

FIG. 1 shows a pictorial view of a double injection diode;

FIG. 2 shows the current-voltage characteristic curve for the double injection diode shown in the drawing according to FIG. 1;

FIG. 3 shows a sectional side view of the double injection diode shown in the drawing according to FIG. 1 together with an integral light emitting diode;

FIG. 4 shows a cross-point switch according to the invention which utilizes double injection diodes as opto-electronic switches;

FIGS. 5A and 5B show respectively a part plan and sectioned side view of a practical arrangement for the cross-point switch shown in the drawing according to FIG. 4;

FIGS. 6A and 6B show respectively a part plan and sectioned side view of a further practical arrangement for the cross-point switch shown in the drawing according to FIG. 4; and

FIG. 7 shows a part plan view of another practical arrangement for the cross-point switch shown in the drawing according to FIG. 4.

Referring to FIG. 1, a pictorial view of a double injection diode is shown which comprises a substrate 1 of semiconductive material in which the density of the injected carriers is greater than the free carrier density at normal operating voltages, for example, semi-insulating gallium arsenide having a resistivity of the order of 10^8 ohms/cm. onto one face of which two thin film metal injection contacts 2, for example, of gold or aluminum are formed to leave a gap 3 therebetween. The metal films are produced by evaporation of metal in vacuo onto a suitably prepared and masked gallium arsenide sub-

strate. Wires are attached to the injection contacts 2 by either soldering, microwelding or thermocompressive bonding.

The semiconductive device shown in the drawing according to FIG. 1 operates according to the "double injection" theory which assumes that if both holes and electrons can be injected and easily transported across a semiconductor crystal, very much higher currents can be made to flow than in the case of single injection, as the two carriers neutralize each other's space charge.

It should be noted that the two metal injection contacts 2 shown in the drawing according to FIG. 1 could be located on opposite faces of the high resistivity gallium arsenide substrate 1.

The current-voltage characteristic curve for a double injection diode of the type shown in the drawing according to FIG. 1 is shown in the drawing according to FIG. 2. There is a breakdown voltage V_B below which negligible current flows and above which a high conductivity region exists. A negative resistance region separates the two states.

If the diode is biased to a voltage V_1 which is near to the breakdown voltage V_B , and a pulse of light of suitable wavelength is caused to fall on the diode, the breakdown voltage V_B is reduced to a value lower than V_1 and the diode switches rapidly into the high conductivity state. If the value of the voltage V_1 is suitably chosen, removal of the light would allow the device to return to its low conductivity state.

Past the negative resistance portion of the curve the voltage remains nearly constant as the current increases to a few milliamperes. The impedances of the single carrier and double carrier regimes differ by about 5 or 6 orders of magnitude, from 10 M Ω to less than 100 Ω .

The double injection diode combined with a light emitting diode or other light source which may be used as a pulsed light emitter will give opto-electronic circuits which could provide gating facilities on pulse circuitry, or switching action. A thin film double injection diode together with an integral light emitting diode is shown in sectional side view in the drawing according to FIG. 3 and comprises the double injection diode shown in the drawing according to FIG. 1 having an N-type gallium arsenide layer 4 epitaxially deposited on the undersurface of the substrate 1. The outer face of the layer 4 contains a P-type diffused region 5 thereby providing a P-N junction and the light emitting diode. Contact areas 6 and 7 are respectively formed onto the region 5 and the layer 4 to which wires are attached to provide the means for suitably biasing the P-N junction i.e. the contact area 6 is made the positive terminal and the contact area 7 is made the negative terminal.

The double injection diode shown in the drawing according to FIG. 1 will as previously stated switch rapidly into a high conductivity state when a pulse of light of suitable wavelength is caused to call on the diode provided the diode is suitably biased. The diode will remain in the high conduction state when the light is removed provided the bias voltage V_1 is made greater than the voltage required to maintain the diode in its high conduction state.

The double injection diode can be made to return to its high impedance state by lowering the bias voltage V_1 momentarily below the maintaining voltage V_M when the diode is in darkness.

When the double injection diode is in the high conductivity state, DC currents of several milliamperes can be passed which can be modulated with AC signals of frequency in excess of 20 kc./sec. with negligible distortion of the signal. Speech currents can therefore be passed through the diode.

A matrix of double injection diodes may be arranged to provide a cross-point switch as shown in the drawing according to FIG. 4 which for purposes of illustration shows a 10x10 matrix. The vertical strips 8 represent common connections to one terminal of 10 devices, and the horizontal strips 9 represent common connections to the other terminal of ten devices, so that at each crossover point a double injection diode is present.

The horizontal strips 9 carry a potential equal to the bias potential V1, and the vertical strips 8 go to one side of the electrical supply, for example earth potential, via suitable impedances 10.

By arranging a light system such that a light signal is applied discretely to any one of the double injection diodes in the system, then the selected diode will transfer into the high conduction state, and speech signals for example can then be transmitted through the circuit so made. Once current flows in any one diode in one of the vertical strips 8 no other diode in that vertical strip or column can be transferred into the high conduction state even if a light signal is applied to it, because the common impedance 10 ensures that all the diodes in that column now have a voltage equal to the maintaining voltage VM biasing them.

FIGS. 5A and 5B show respectively a part plan and sectioned side view of a practical arrangement for the cross-point switch shown in the drawing according to FIG. 4 in which the double injection diodes which are provided at each of the crossover points have the two injection contacts on the same side of the substrate 1.

Referring to FIGS. 5A and 5B, the double injection diodes at each of the crossover points are provided by the vertical strips 8 which form one injection contact, the horizontal strips 9 which form the other injection contact, and the substrate 1.

The vertical strips 8 which are insulated from the horizontal strips 9 at each crossover point by means of the insulating regions 12 have L-shaped projections 11 at each crossover point which are located in close proximity to the horizontal strips 9 to provide narrow gaps 3 of the order of 0.1 mm.

The L-shaped projections 11 could form part of the horizontal strips 9 instead of the vertical strips 8, in fact, both the vertical and horizontal strips 8 and 9 could be provided with extension pieces such that a diode gap is formed therebetween.

The vertical and horizontal strips 8 and 9 are thin films of metal deposited onto a clean surface of the substrate 1, for example, of semi-insulating gallium arsenide, germanium or silicon, after appropriate masking by evaporation in vacuo. In order to provide the arrangement shown in the drawings according to FIGS. 5A and 5B a three stage process would be involved, the vertical strips 8 and the L-shaped projections 11 would first of all be deposited onto the substrate 1, followed by the insulating regions 12 and finally the horizontal strips 9, the substrate and the deposited films being suitably masked before each of the three stages.

When semi-insulating gallium arsenide is used as the substrate 1, suitable metals to form the vertical and the horizontal strips, 8 and 9 and the L-shaped projections 11 are gold and aluminum.

In this arrangement the light system would be arranged to direct the light onto the gap 3 of the selected diode.

In the drawings according to FIGS. 6A and 6B a part plan view and sectioned side view of a further practical arrangement for the cross-point switch shown in the drawing according to FIG. 4 is shown and in this arrangement the vertical strips 8 are deposited onto one side of the substrate 1 whilst the horizontal strips 9 are deposited onto the other side of the substrate 1, the diode gaps being provided at each crossover point between the strips 8 and 9. Again, the vertical and horizontal strips 8 and 9 are thin films of metal which have been deposited onto the substrate 1 by evaporation in vacuo and if the substrate 1 is of semi-insulating gallium arsenide, the metal used for the strips 8 and 9 may be provided by either gold or aluminum. In this arrangement the light system would be arranged to direct the light onto the side of the diode gap where the vertical and horizontal strips 8 and 9 cross.

Alternatively, the strip which is uppermost could be made semitransparent, for example, a thin film gold strip 100 Angstroms thick would be semitransparent, or a hole could be left at each crossover point in the uppermost strip, so that the light may be shone from above directly into the gap region at the selected crossover point.

In the drawing according to FIG. 7 a part plan view of another practical arrangement for the cross-point switch shown in the drawing according to FIG. 4 is shown. This arrangement is similar to the one shown in the drawings according to FIGS. 5A and 5B except diffused regions 14 and 15 in the substrate 1 are used instead of the metal films to provide the diode gap 16. The diffused regions 14 are N-type and the diffused regions 15 are P-type. The vertical and horizontal strips 8 and 9 which are respectively used as connecting conductors for the diffused regions 14 and 15 are thin films of metal which are deposited onto the substrate 1 by evaporation in vacuo after the P-type regions 15 and the N-type regions 14 have been produced by the diffusion of suitable dopants into the surface of the substrate 1 after appropriate masking.

The insulating regions 12 are deposited after appropriate masking at each crossover point on the vertical strips 8 before the horizontal strips 9 are deposited in order to insulate the vertical strips 8 from the horizontal strips 9. The light system used with this arrangement would be arranged to direct the light onto the gap 16 between the diffused regions 14 and 15 of the selected diode.

The vertical and horizontal strips 8 and 9 shown in the drawings according to FIGS. 6A and 6B could also be provided by diffusion using, for example, a P-type dopant for the vertical strip 8 and an N-type dopant for the horizontal strip 9 thereby providing at each crossover point between the strips 8 and 9 the diode gaps. It may in this instance be necessary to deposit onto the top of each diffused strip thin metal films to act as connecting conductors.

In the arrangements shown in the drawings according to FIGS. 5A, 5B and 7 the substrate could be provided by a slice of gallium arsenide ingot, or an epitaxially deposited film.

The arrangements shown in the drawings according to FIGS. 5A and 5B and FIG. 7 could be provided with a matrix of electroluminescent devices, the matrix pattern being made so that one electroluminescent device can be positioned so that its light emission falls either directly onto the light sensitive area i.e. the diode gap, or onto such an area via a light guide. For example, an integral light source at each of the crossover points in the form of, for example, a light emitting diode would serve this purpose. The device shown in the drawing according to FIG. 3 would be typical of the sectioned side view through each crossover point in such an arrangement. In order to provide the arrangement with the integral light emitting diode it would be necessary to epitaxially deposit an N-type gallium arsenide layer onto the under surface of the substrate 1, diffuse the regions of the N-type layer at each crossover point with a P-type dopant to provide the P-N junction and thereby the light emitting diode and deposit onto the N-type layer and the P-type diffused regions at each crossover point contact areas to which wires would be attached to provide the means for suitably biasing the P-N junction when required.

Another system of illuminating the double injection diodes discretely at each crossover point would be to use fiber optics. The fibers leading to the individual diodes are clad with a black opaque outer layer, and the ends of the fibers are located in close proximity to the diodes so as to ensure that only one diode is illuminated by each fiber. Accurate indexing of the light source onto the receiving ends of the light fibers could be arranged in several ways, for example, a special form of cathode-ray tube (CRT) could be used for this purpose.

In the CRT system the receiving ends of the light fibers are incorporated into a solid block of suitable material where they are accurately located in a set pattern such that their receiving ends are exposed. That face of the solid block which is composed of the receiving ends of the light fibers is provided with a phosphor layer and acts as the inner surface of the CRT screen.

By feeding coordinate signals onto the gun electrode system of the CRT in order to deflect the focused electron beam to a given point on the CRT's phosphor screen, the light spot which is produced is picked up by the receiving end of one of

the fibers and transmitted to one of the diodes on the crossbar switch.

Alternatively, a fixed light spot could be used with the cross-point switch mounted on a tape controlled table or a coordinate table, so that a particular diode could be automatically positioned beneath the light source. The positioning of the tape controlled table would be in accordance with the information contained in the tape and the positioning of the coordinate table would be in accordance with the coordinate signals applied thereto. A digital-indexed light deflector could be used to direct the light source to the individual diodes. In the digital-indexed light deflector system an electro-optic device allows fast (1μ sec) random directing of an intense, coherent laser beam towards any of a large number of different positions.

It is to be understood that the foregoing description of specific examples of this invention is made by way of example only and is not to be considered as a limitation on its scope.

What we claim is:

1. A matrix of double injection diodes arranged on a common substrate of semiconductor material, said material having an injected carrier density greater than the free carrier density at normal operating voltages, said matrix providing a light sensitive cross point switch comprising:

a plurality of columns of conductors in contact with one side of said substrate;

a plurality of rows of conductors in contact with said one side of said substrate in a direction transverse to the direction of said columns and crossing over said columns, at least one of said row and column conductors at each cross over point extending over a surface portion of said substrate, a part of each conductor of said row being separated from a part of an associated conductor of said column by another surface portion of said substrate, said other surface portion forming a diode gap for a double injection diode associated therewith, said row and column conductor parts forming two metal injection contacts for said double injection diode associated therewith;

an insulating region disposed between said rows and columns of conductors at each crossover point; and means for biasing said double injection diodes to a voltage level less than the voltage required to switch said double injection diodes from their normally low conduction state to a high conduction state, said double injection diodes responding to the application of suitable incident light to

switch into said high conduction state.

2. A cross-point switch as claimed in claim 1 wherein the double injection diodes in each of the rows are provided with a common connection for one of their two injection contacts, and wherein the double injection diodes in each of the columns are provided with a common connection for the other of their two injection contacts.

3. A cross-point switch as claimed in claim 2 wherein said biasing voltage for said double injection diodes is applied thereto by said row common connections which are connected to suitable electrical supply means.

4. A cross-point switch as claimed in claim 3 wherein means are provided to ensure that at any one time only one of the double injection diodes in any one column can be switched into conduction by the application of said incident light.

5. A cross-point switch as claimed in claim 4 wherein said means to ensure that at any one time only one of the double injection diodes in any one column can be switched into conduction by the application of said incident light are provided by impedance networks which are connected between column common connections and one side of the electrical supply.

6. A cross-point switch as claimed in claim 1 wherein said extension piece is L-shaped and extends from one of said metal conductors, the free end of said L-shaped extension piece and the other metal conductor forming said diode gap.

7. A cross-point switch as claimed in claim 1 wherein said substrate is provided from among semi-insulating gallium arsenide, silicon and germanium.

8. A cross-point switch as claimed in claim 1 wherein said metal conductors are provided from between gold and aluminum, said substrate is of the semi-insulating gallium arsenide.

9. A switching system which utilizes a cross-point switch as claimed in claim 1 including an integral light source at each of the crossover points.

10. A switching system as claimed in claim 9 wherein said integral light source at each of the crossover point is provided by a light emitting diode.

11. A switching system as claimed in claim 10 wherein said light emitting diodes are provided by semiconductive devices formed from one layer of epitaxially deposited semiconductive material which is formed on that face of said body of semiconductive material which is opposite said face on which said plurality of metal conductors are deposited.

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