SEMICONDUCTOR SIGNAL TRANSLATING DEVICE

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FIG. 1

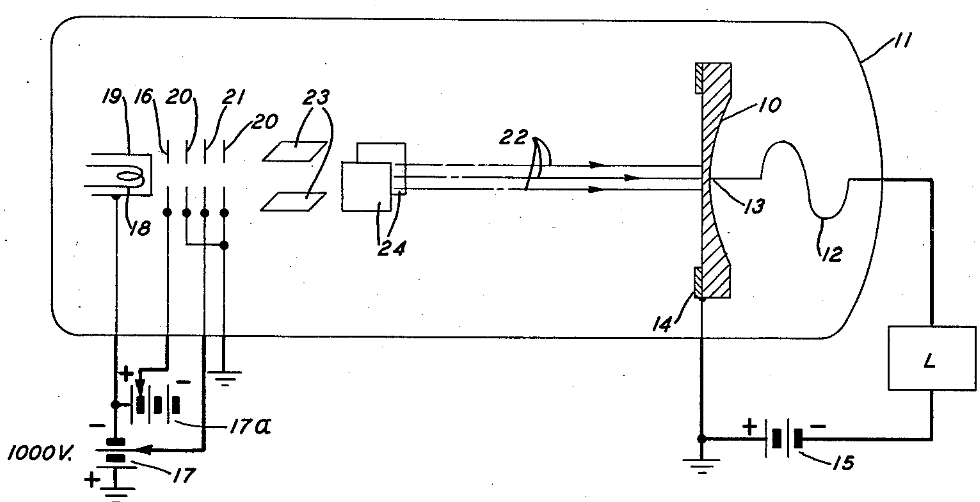


FIG. 2

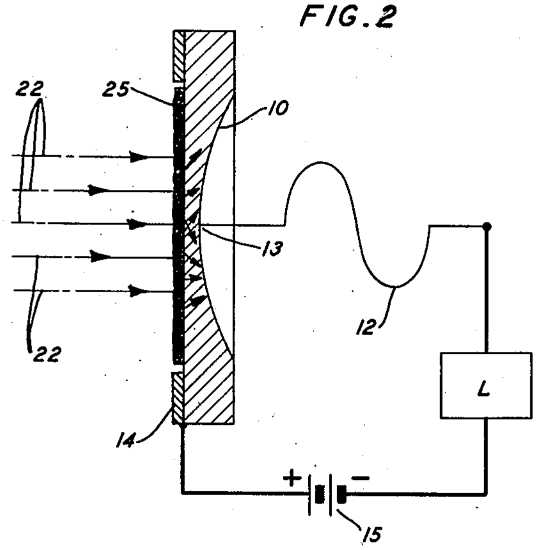


FIG. 3

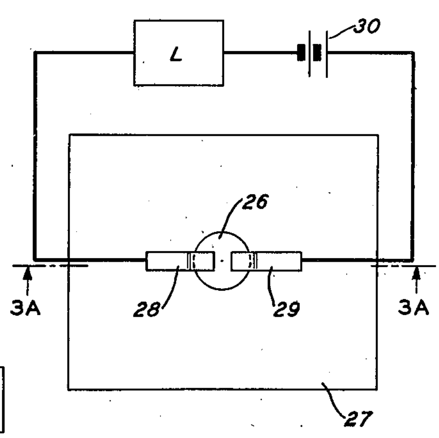
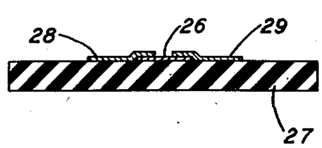


FIG. 3A



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March 18, 1952 W. E. KIRKPATRICK ET AL 2,589,704

SEMICONDUCTOR SIGNAL TRANSLATING DEVICE

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FIG. 4

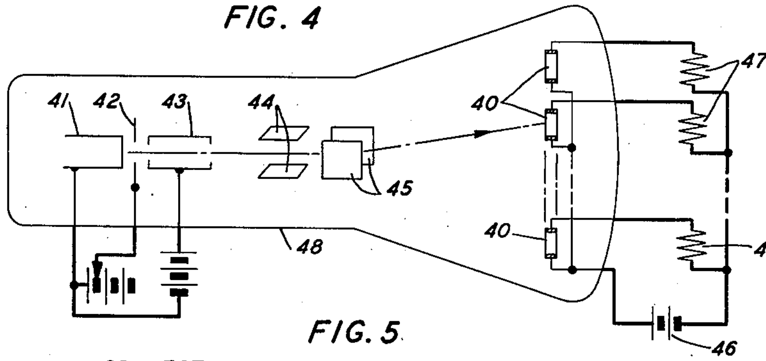

FIG. 5

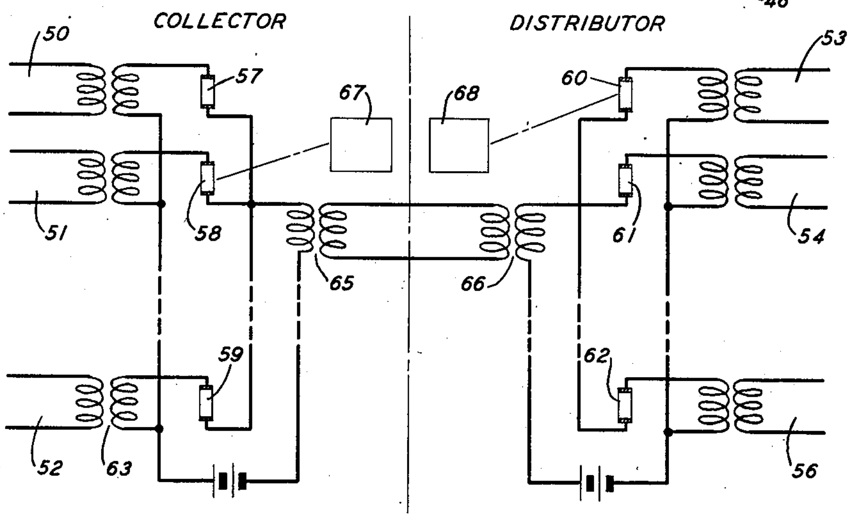

FIG. 6

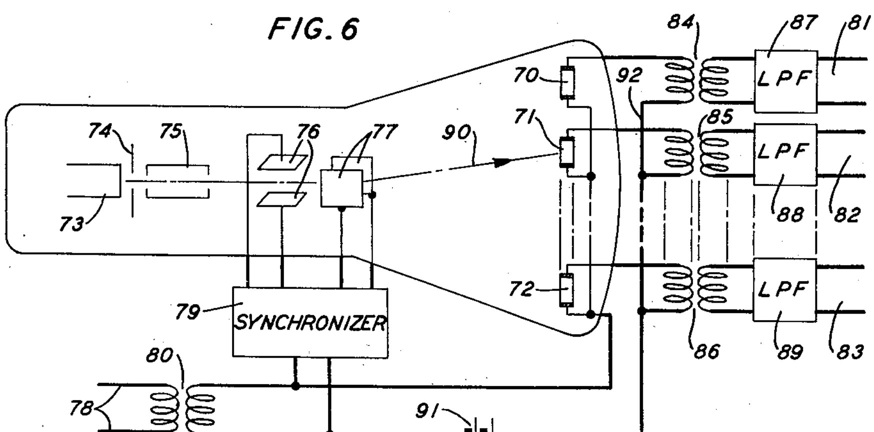

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FIG. 7

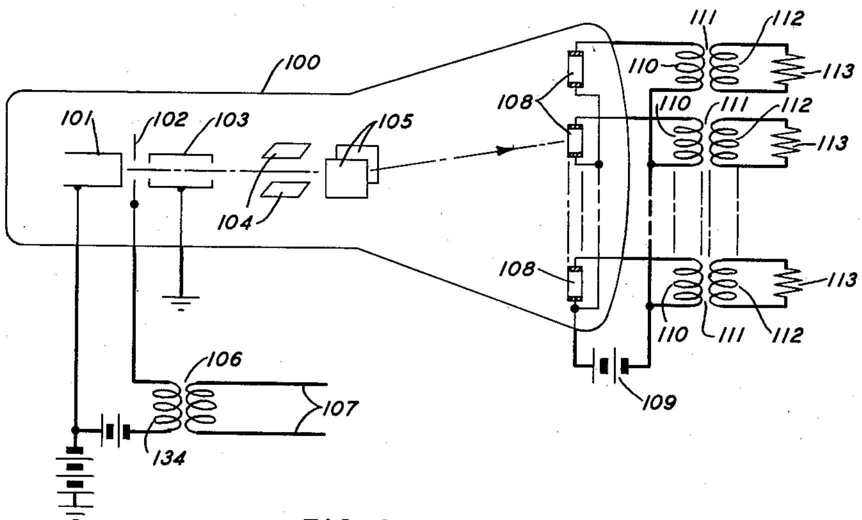
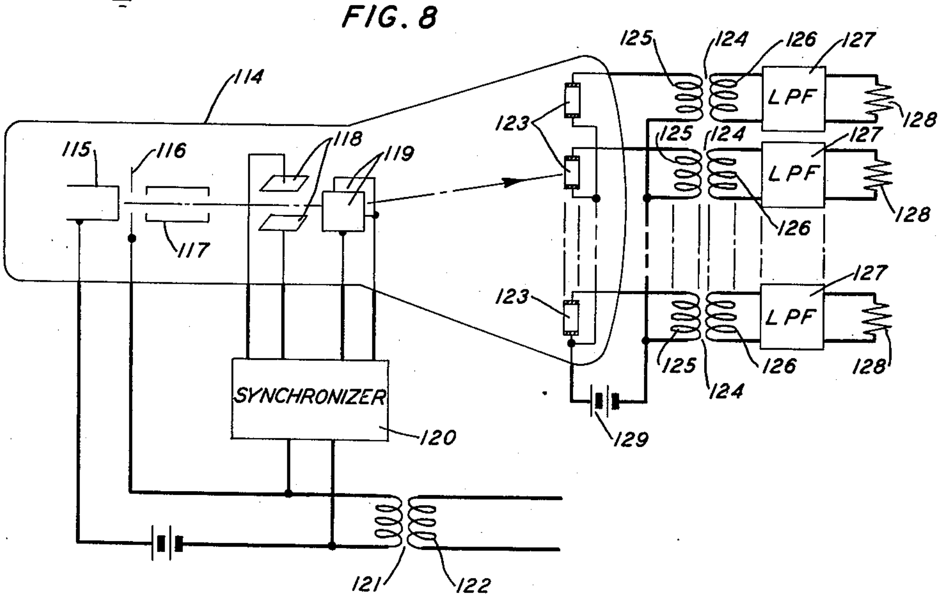


FIG. 8



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UNITED STATES PATENT OFFICE

2,589,704

SEMICONDUCTOR SIGNAL TRANSLATING DEVICE

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17 Claims. (Cl. 315—1)

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This invention relates to devices for the translation of electric currents and more particularly to apparatus for the translation of electric currents through the utilization of electron bombarded semiconductor material.

It has been found that the bombardment of certain semiconductive crystals with an electron stream will result in the conductivity of the semiconductive crystals becoming considerably enhanced. Each bombarding electron, under certain conditions, will excite as many as several hundred internal secondary electrons thus causing the internal secondary electron emission ratio to be greatly in excess of unity. Under the action of an applied electric field these internal secondary electrons act as carriers for an electric current.

One of the general objects of this invention is to translate electric currents, utilizing electron bombardment induced conductivity in semiconductors.

Another object of the invention is to obtain a high ratio of the conductance of the electron bombarded material to the conductance of the material when not bombarded by electrons.

Further objects of the invention are to provide electron beam deflection switching and amplifying devices utilizing electron bombardment induced conductivity in semiconductors.

Other objects of the invention are to enable the utilization of electron bombarded semiconductors in selective circuit arrangements having no moving parts and the utilization of electron bombarded semiconductors in a time division multiplex distributor tube having no moving parts.

In one illustrative embodiment of the invention, a spring wire is caused to make a point contact on one side of a thin wafer-shaped semiconductive material element. A base connection of a conductive material is connected to the semiconductive material at a distance from the point of contact of said spring wire. Electron bombardment of the semiconductive material causes a greatly enhanced current to flow through the semiconductive material when the base connection is made positive with respect to the contact.

A similar result is obtained by coating a portion of the semiconductor material with a photoluminescent material and bombarding the photoluminescent material with electrons.

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In another illustrative embodiment of the invention, a thin layer of semiconductive material is formed upon a base of insulating material. Contacts are formed so that each contact will overlap substantially opposite edges of the semiconductive material. A potential is applied across the contacts. Electron bombardment of the semiconductive material will increase the conductivity thereof which will allow a flow of current through the semiconductive material of a magnitude much greater than that of the bombarding electron stream.

In a further embodiment of the invention, a plurality of any one of the semiconductor elements described hereinabove are placed within a single envelope. Opposite this plurality of semiconductive elements is positioned a means for generating an electron stream which can be directed upon any of the semiconductive elements. In such an arrangement, an incoming signal can be impressed upon the electron beam causing variations therein. These variations will be reflected in the amount of current flowing through the semiconductive element upon which the electron beam is focused. Current amplification will result inasmuch as the current in the semiconductor resulting from the electron bombardment is considerably greater than the electron beam current itself. A feature of this arrangment lies in its adaptability to switching functions. Each semiconductive element within the envelope can be individual to a particular line. The application of the proper deflection voltages upon the deflector plates associated with the electron beam will cause the electron beam to focus upon a particular semiconductive element thus causing the semiconductive element to become conductive. The use of two of these devices, one for a plurality of incoming circuits, and a second for a plurality of outgoing circuits will allow the connection of any one of the incoming circuits to any one of the outgoing circuits.

Another feature of this embodiment of the invention lies in its application to time division multiplex circuits. The incoming signal pulses can be applied to the electron beam and the sweep of the electron beam across a plurality of semiconductive elements can be synchronized with the incoming pulses. It is to be noted that in none of these arrangements of the invention are there any moving parts.

The above-mentioned and other objects and features will be more clearly understood from the following description when read in conjunction with the drawings in which:

Fig. 1 illustrates a device constructed in accordance with this invention including a dimple-type semiconductor;

Fig. 2 illustrates a modification of the device shown in Fig. 1 wherein the semiconductor wafer has one surface partially covered with a phosphor layer;

Fig. 3 illustrates an embodiment of the invention particularly adaptable to switching applications;

Fig. 3A is a side view of Fig. 3 taken along the line 3A—3A in Fig. 3;

Fig. 4 illustrates a switching and amplifying device incorporating a plurality of the semiconductive elements;

Fig. 5 is a diagram illustrating a switching arrangement incorporating the semiconductive units whereby any one of a number of inputs may be connected to any one of a plurality of outputs;

Fig. 6 illustrates a time division multiplex application utilizing electron bombarded semiconductive elements;

Fig. 7 shows a switching and amplifying circuit arrangement; and

Fig. 8 shows another form of a time division multiplex distributor circuit having a control grid-impressed signal input.

Referring now to Fig. 1 there is shown a single dimple-type wafer 10 of germanium, cadium sulphide or other suitable material enclosed within envelope 11. Spring wire 12 makes rectifying contact with wafer 10 at point 13. Element 14 is a ring of a conductive material, such as rhodium or copper for example, and makes ohmic contact with wafer 10. A potential from a source 15 is applied between point contact 13 and conductive base 14. The electron beam generating means is comprised of a heater element 18, cathode 19, accelerating and focusing anodes 20 and 21 and control grid 16. Battery source 17*a* supplies bias to control electrode 16 and battery 17 supplies bias to the accelerating and focusing electrodes 21 and 20. The electron beam, shown as lines 22, is directed between deflector plate pairs 23 and 24. The electron beam is caused to impinge upon the wafer 10 at a point preferably directly opposite point contact 13 since this has been found to produce the greatest conductivity in the semiconductor element 10.

The useful output load, which may be a vacuum tube input circuit, a relay, or other device, is represented by the element L.

In a typical set of operating conditions a 10 microampere electron beam accelerated by 10,000 electron volts energy is caused to impinge on the germanium wafer. With 10 volts applied across the germanium wafer in the non-conducting direction, the current flow therethrough is approximately 550 microamperes, or about 55 times the value of the electron beam current.

It is to be noted that the ratio of electron bombardment induced current to the electron beam current increases rapidly as the voltage bias applied across the wafer increases until said voltage bias reaches about 10 volts whereupon said ratio becomes substantially constant with increasing bias voltage. This is true of any of the embodiments of the invention herein described.

Referring now to Fig. 2 there is disclosed a single dimple wafer-type semiconductive element which may be substituted for the one shown on Fig. 1. Spring wire 12 makes contact at point 13. Base connection 14 is connected to the wafer 10 at a distance from point contact 13. On the side opposite the point contact 13 a photoluminescent material or phosphor layer is coated upon the surface of the wafer 10. The electron beam represented by the lines 22 strikes the phosphor layer to produce photons which will cause the semiconductive material to become more conductive. Battery 15 supplies the potenital across base contact 14 and point contact 13. Element L represents the useful load.

As mentioned before, the presence of the phosphor layer on the semiconductor will give rise under electron bombardment to the ejection of photons from the phosphor, some of which will in turn penetrate the semiconductor upper layers to excite electrons from the filled energy band to the conduction band.

Fig. 2 shows this double transfer in pictorial fashion. The impinging electron beam 22 strikes the phosphor layer 25 causing the release of light quanta each of energy hv, where h is Planck's constant and v is the frequency of the emitted light. Some of these photons will penetrate the semiconductor surface where they will give up their own energy to excite electrons from the filled energy band to the conduction band of the semiconductor.

Despite the double energy exchange involved and the loss of some light energy escaping from the phosphor surface into areas other than that occupied by the semiconductor, the results are quite similar to those obtained with direct electron bombardment of the semiconductors shown in Fig. 1.

In Figs. 3 and 3A a third device utilizing semiconductor material is illustrated. A thin film 26 of a semiconductor such as germanium or cadium sulfide is deposited on a base 27 of an insulator material. Metal contacts 28 and 29 are then applied so as to overlap parts of the semiconductor element 26. Battery 30 is applied across contacts 28 and 29. The load is represented by element L. In the absence of electron bombardment of semiconductor element 26, the resistance of the semiconductor element is very high so that only negligible current flows through load L. When semiconductive element 26 is bombarded by electrons, however, the conductivity of the element becomes considerably enhanced and allows a much greater current to flow through load L to accomplish the desired function.

A preferred thickness of the semiconductor element 26 is that thickness of material which the impinging electron beam will just penetrate. For a 1000-volt beam this thickness is of the order of 10^{-5} centimeters. This can be obtained by evaporating a thin film of the semiconductor such as germanium onto the flat insulator. The contact electrodes can be evaporated, plated, or otherwise deposited strips on top or underneath the semiconductive film. In some cases it is advantageous to deposit some impurity activator material, such as tin for example, along with the semiconductor to assure that the thin film of semiconductor material has the same qualities as the bulk material.

Fig. 4 shows a switching device embodying the invention. Included within a single envelope 48 is means for generating and directing an electron beam comprising cathode 41, control grid 42, accelerating and focusing anodes 43 and deflection plate pairs 44 and 45. Also included in the envelope are bombardment induced conductivity elements 40 connected in parallel to battery 46. Each semiconductive element 40 has associated therewith a load element 47. The electron beam may be focused by well known means upon any of the semiconductive elements 40 causing the element to become conductive. As a simple switching device, load 47 can be a relay winding with sensitivity adjusted so that the relay will operate when the electron beam is focused on its associated semiconductor element and not operate otherwise.

Fig. 7 shows a switching and amplifying device. Envelope 100 comprises the electron beam generating means consisting of cathode 101, control electrode 102, and focusing and accelerating electrode 103. Deflection of the beam to the desired bombardment induced conductivity elements 108 is obtained by applying deflection potentials to deflection plate pairs 104 and 105. Each semiconductive element is connected in series with an individual primary 110 of an individual output transformer 111. Each secondary 112 is connected to an individual useful output load 113. The input signal to be switched to one of the output channels is applied to the primary 107 of input transformer 106. The output 134 of this transformer acting through the medium of control grid 102 serves to vary the beam current passing to the semiconductive elements in accordance to the signal. Since the conductivity of semiconductive elements 108 when bombarded by an electron stream is proportional to the intensity of the electron stream within certain limitations, a signal impressed on the electron beam source causing variations in the intensity of the electron beam will be reflected in the amount of current flowing through the semiconductive elements 108. Furthermore, since the amount of current flowing through an electron bombarded element 108 due to electron bombardment is of a magnitude considerably greater than the current of the electron stream bombarding the element any signal impressed on the electron beam source to vary the intensity of the electron beam will be amplified by means of the semiconductive devices 108.

Fig. 5 illustrates a circuit for switching or connecting any one of a first plurality of lines such as 50, 51 or 52 to any one of a second plurality of lines such as 53, 54 or 56. Elements 57, 58, 59, 60, 61 and 62 are electron bombardment induced conductivity elements such as shown in Figs. 1, 2 or 3. Associated with each of these semiconductive elements is a transformer such as 63 connecting each of the electron-bombardment induced conductivity elements to one of the plurality of lines. The first plurality of lines is connected to the second plurality of lines through a link element and transformers 65 and 66. Since elements 57, 58, 59, 60, 61 and 62 are normally non-conductive for all practical purposes when not bombarded by an electron stream, there will, in effect, be no coupling between any of the first plurality of lines 50, 51 or 52 and any of the second plurality of lines 53, 54, and 56. Elements 67 and 68 are electron beam generating means. Electron generating means 67 will be included in the same envelope with semiconductive elements 57, 58 and 59, and electron generating means 68 will be included in the same envelope as semiconductive elements 60, 61 and 62. The focusing of the electron beam generated by electron beam generating means 67 on any one of semiconductive elements 57, 58 and 59 and the focusing of the electron beam from source 68 upon any one of semiconductive elements 60, 61 or 62 will result in the coupling of the two lines associated with the semiconductive elements. Thus it is shown in Fig. 5 that any one of the first plurality of lines 50, 51 or 52 can be connected to any one of a second plurality of lines 53, 54 or 56.

It should be noted that the individual operations of collecting and distributing in Fig. 5 are done by two completely identical tubes so that either tube may be used alone as a collector or distributor. Fig. 5 shows the use of two such tubes back-to-back for the combined operation of collecting and distributing.

In Fig. 6 there is illustrated another switching device illustrative of the invention. Included within a single envelope are electron bombardment conductivity elements 70, 71 and 72 and a means for generating an electron beam which will be capable of sweeping elements 70, 71 and 72. The electron beam generating means comprises cathode 73, control electrode 74, accelerating and focusing anode 75, and deflection plate pairs 76 and 77. A time division multiplex input signal is applied on leads 78 and is coupled to a synchronizer 79 through transformer 80. Semiconductive elements 70, 71 and 72 are also coupled to input leads 78 through transformer 80. Each of elements 70, 71 and 72 is further coupled to an output line such as 81, 82 and 83, respectively, through transformers 84, 85 and 86, respectively. Each of lines 81, 82 and 83 has an associated low pass filter designated as 87, 88 and 89, respectively. When not bombarded by an electron stream, elements 70, 71 and 72 are non-conductive for practical purposes, as far as this particular circuit is concerned. Assume, however, that the electron beam 90 is focused on element 71. This will cause element 71 to become conductive in a manner similar to that described with respect to Figs. 1, 2 and 3. Line 82 will be coupled to input leads 78 through low pass filter 88, transformer 85, element 71, battery 91, conductor 92 and transformer 80. The synchronizing or marker signal contained in the input signal impressed on lead 78 triggers synchronizer 79 and so deflects the beam to the appropriate semiconductive unit such as 71, which working through a low pass filter such as 88 to a line 82 distributes the incoming time division multiplex signal to the correct line.

This system may be operated in the reverse fashion as a sampling tube for this operation. The individual line signals are fed through leads 81, 82 and 83 and coupled to the common circuit 78 in time sequence by the scanning electron beam 90. In this case, the synchronizer 79 is driven from an external source, not shown, and supplies energy both to the deflection system and to the time division multiplex output in the form of a marker pulse.

Fig. 8 shows another form of time division multiplex distributor in which the input signal is impressed on the control grid 116. Envelope 114 comprises this grid plus additional beam forming electrodes consisting of cathode 115 and focusing and acceleration anodes 117. Deflection plate pairs 118 and 119 are controlled by synchronizer 120 to direct the beam to the appropriate semiconductive element 123 in accordance with marker energy supplied by the input signal.

Each bombardment induced conductivity element 123 has one side connected in common to a voltage source 129. The other side of each element is connected through individual primaries 125 of transformers 124 to the other side of the voltage source. Secondaries 126 are each connected through low pass filters 127 to useful loads 128. The input time division multiplex signal consisting of information plus marker energy is introduced on primary 122 of input transformer 121. Marker energy is separated and fed to the synchronizer while the communication information is fed to the control grid where it varies the beam current in accordance with the incoming information. Again the action of the semiconductive element is to provide current multiplication of the impinging beam current.

It is understood that the devices herein described are merely some preferred embodiments of the invention and that various changes may be made in arrangement of circuit elements and changes in shape of various parts of the structure and substitution of materials without departing from the spirit or scope of the invention.

What is claimed is:

1. A signal translating device comprising a body of semiconductive material, a surface layer of phosphorescent material on a portion of said body, electrical connections to two spaced regions of said body, an output circuit coupled to said connections, means for projecting an electron stream against said layer of phosphorescent material, means for varying the intensity of said electron stream, and means for applying a potential across said connections.

2. A signal translating device comprising a body of semiconductive material, an ohmic base connected to said body, a rectifying connection to said body at a region thereof spaced from said base connection, and means for directing an electron beam against the surface of said body in proximity to said rectifying connection.

3. A signal translating device in accordance with claim 2, comprising means for applying a potential to bias said rectifying connection with respect to said base connection so that the ratio of the electron bombardment induced current of the semiconductive material to the electron beam current is substantially constant.

4. A signal translating device in accordance with claim 2 wherein said body is of cadmium sulfide material.

5. A signal translating device comprising a wafer-shaped body of germanium material, a conductive metallic base connected to said body, a rectifying connection to said body at a region thereof spaced from said base connection, and means for directing an electron beam against the surface of said body at a region in proximity to said rectifying connection.

6. A signal translating device in accordance with claim 5, comprising a potential means biasing said rectifying connection with respect to said base connection so that the ratio of the electron bombardment induced current of a semiconductive material to the electron beam current is substantially constant.

7. A signal translating device comprising a wafer-shaped body of semiconductive material, a point contact bearing against one face of said body, an ohmic connection to said body at a region spaced from said point contact, a utilization circuit connected between said point contact and said ohmic connection, a coating of phosphorescent material upon the opposite face of said body, and means for projecting an electron beam aainst said phosphorescent coating.

8. A signal translating device in accordance with claim 7 wherein said wafer-shaped body is of germanium material.

9. A signal translating device in accordance with claim 7 wherein said body is of cadmium sulfide material.

10. In combination, a plurality of switching circuits, each of said circuits having a switching device therein, each of said switching devices comprising a wafer-shaped semiconductive body and contacts connected to said body, means to apply a potential to said contacts, an output circuit associated with each of said switching circuits, and means to selectively project an electron beam upon any one of said bodies.

11. A combination in accordance with claim 10 wherein said body is of germanium material.

12. A combination in accordance with claim 10 wherein said body is of cadmium sulfide.

13. In combination, a plurality of input circuits, a plurality of output circuits, a plurality of switching devices, one of said switching devices individual to each of said input and output circuits, a third circuit coupling all of said plurality of input circuits to all of said plurality of output circuits, each of said switching devices comprising a wafer-shaped semiconductive body having two contacts connected thereto, means to apply a potential across each of said switching devices, a first means for selectively projecting a first electron beam on any of said switching devices associated with said plurality of input circuits, and a second means for selectively projecting a second electron beam upon any of said switching devices associated with said plurality of output circuits.

14. A combination in accordance with claim 13 wherein said semiconductive body is of cadmium sulfide material.

15. In combination, a plurality of input circuits, a plurality of output circuits, a plurality of switching devices, each of said switching devices coupled to one of said input and output circuits, a third circuit coupling all of said switching devices associated with said plurality of input circuits to all of said switching devices associated with said output circuits, each of said switching devices comprising a thin wafer-shaped semiconductive body of germanium material having two contacts connected thereto, means to apply a potential across the contacts of each of said switching devices, a first means for selectively projecting a first electron beam on any of said switching devices associated with said plurality of input circuits, and a second means for selectively projecting a second electron beam upon any of said switching devices associated with said plurality of output circuits so that any of said input circuits can be connected to any of said output circuits.

16. A time division multiplex circuit comprising an input circuit, a plurality of output circuits, a plurality of switching devices, one of said switching devices individual to each of said output circuits and connecting the associated output circuit to said input circuit, each of said switching devices being coupled to its associated output circuit, means to selectively project an electron beam on any one of said switching devices, each of said switching devices comprising a thin wafer-shaped body of semiconductive material having two electrical contacts connected thereto, means to apply a potential across each

of said switching devices, and means to synchronize a sweep of said electron beam with input signals impressed on said input circuit.

17. A signal translating device comprising a body of semiconductive material, electrical connections to two spaced regions of said body, a rectifying junction associated with said body intermediate said electrical connections, an output circuit connected to said connections, means for projecting an electron stream against the surface of said body in proximity to said rectifying junction, means for varying the intensity of said electron stream, and means for applying a potential in the non-conducting direction across said rectifying junction.

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