Jan. 2, 1962 F. W. KAMMERER ET AL 3,015,738

SIGNAL TRANSLATING DEVICE

Filed Oct. 17, 1958

FIG. 1

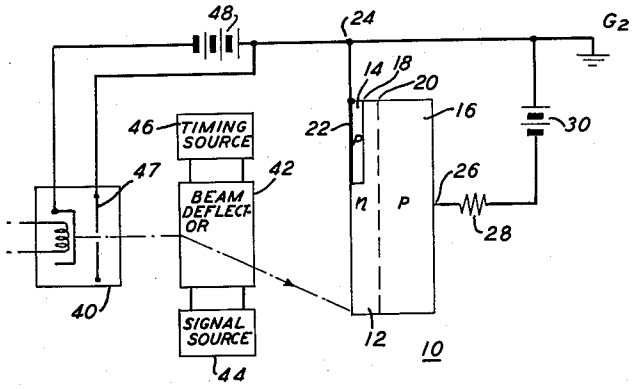
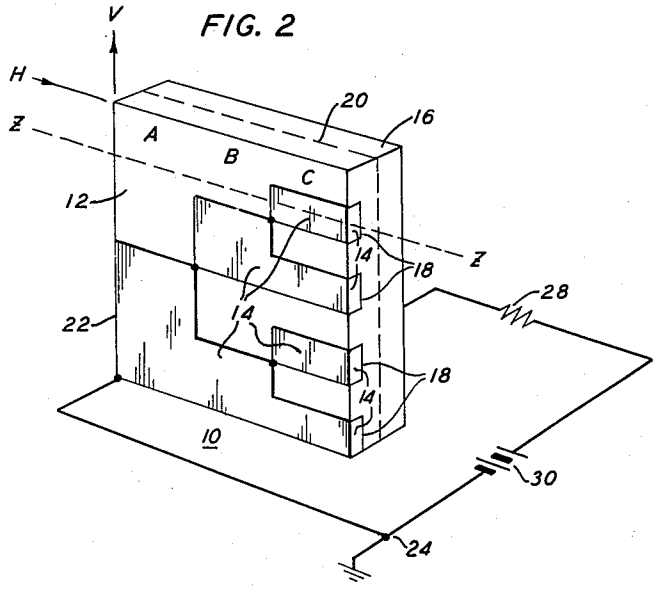


FIG. 2



INVENTORS: F. W. KAMMERER
R. P. RIESZ
R. L. WALLACE, JR.

BY Walter M. Hill

ATTORNEY

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SIGNAL TRANSLATING DEVICE

Fred W. Kammerer, Morristown, Richard P. Riesz, Berkeley Heights, and Robert L. Wallace, Jr., Warren Township, Somerset County, N.J., assignors to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

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This invention relates to switching apparatus and more particularly, in an important aspect, to switching apparatus employing a beam of charged particles in conjunction with a semiconductor target body.

A problem fundamental to switching apparatus is that of achieving both high accuracy and speed in the translation of signals of substantial magnitude. Switches employing a beam of charged particles heretofore have been limited in the achievement of both accuracy and speed by the energy content of the beam itself. Thus, if a signal switching beam current be substantial, that is, if the beam current density be great, the mutual repulsion of the like charged beam particles tends to defocus the beam. Hence a target structure arranged to receive and translate such a beam signal must be of substantial area to account for the coarseness engendered in beam signal information conveyed by deflections of the defocused beam.

With this coarseness comes a necessity for large beam deflections to impart informational significance to the particles incident on a target structure. Such large beam deflections not only require substantial deflecting signals because of the inertia of the many beam particles but require substantial response time as the beam is moved from an initial position to a well-removed desired position.

Conversely, if the switching beam current density be reduced to avoid this defocusing and other associated problems, it immediately follows that the instantaneous beam informational content is reduced as the beam current signal tends to be submerged in spontaneously generated system noise signals. Further, a reduced signal, even if above system noise levels, may necessitate external amplifiers for properly driving utilization circuits. Consequently, information translated through the medium of a charged particle beam may require time-consuming integration processes either to eliminate confusion introduced by spurious noises or to meet external circuit requirements for a high signal level without additional equipment. Whence, following the teachings of the prior art, information translated through a charged particle beam signal may only be translated at a rate lessened by the reduced beam density.

Further, the charged particle beam switching structures of the prior art have been encumbered with the necessity for complex ancillary masks or expensively delicate arrangements of plural particle sensitive target elements for imparting an informational significance to beam translated signals. Such ancillary masks, by virtue of their physical separation from a bombarded target element, have added parallax errors to the other problems which derogate the accuracy of beam signal translation.

A patent to R. W. Sears, No. 2,589,704, granted March 18, 1952, teaches a remarkable stride forward in reducing the required beam current density for translation of a signal against a given system noise background. Sears teaches that an electron incident upon a semiconductor body may dissociate negative electron-positive hole pairs within that body in relation to the velocity of the incidence of the various electrons of that

beam. Sears takes advantage of this phenomenon by providing such a semiconductor body having a rectifying junction and providing appropriate circuitry for collecting the current carriers dissociated by an incident particle beam.

Thus, Sears accomplishes a beam signal detection which effectively multiplies the current density of a particle beam since each of the beam particles is represented in the collecting circuitry by the dissociated charge carriers which in turn are proportioned both to the number of incident electrons and to the velocity with which these electrons strike the semiconductor body. Whence, following the teachings of Sears, the signal carrying charge of a beam electron is multiplied many times over and may enable a substantial reduction in the beam current density required by other portions of a signal utilizing system.

The present invention, however, has for a principal object an even further reduction in this required beam density to enable more precise focusing of a signal translating electron beam, to increase signal translating speed and to heighten signal translating accuracy simultaneously. As a further object and in complement to those enumerated above, the present invention is directed also to the simplification of beam switching structures to reduce beam target size and to eliminate the costly ancillary masks and expensive plural beam target arrangements heretofore required.

For achieving these and other objects the present invention makes capital of the recognition that a charged particle beam may be employed not only as means for establishing current-carrying conditions within a semiconductor body but, as well, may be employed as an integral element in the current-carrying and amplifying processes of which such bodies are known to be capable. The invention turns this recognition to account by directing a charged particle beam against a central portion of a semiconductor body having two oppositely arranged rectifying junctions external to that central body portion. The one of these junctions is reversely biased.

In accordance with a further feature of the invention, a first electrode external to the other junction is connected from the body to a point of substantially fixed potential in common with the beam source and a second electrode, external to the reversely biased junction, connects the semiconductor body through a load impedance to that same point of substantially fixed potential. Thus, following the principles of the invention, the beam current is effectively multiplied many times over in its incidence upon the semiconductor body through the dissociation of electron-hole pairs. At the same time, the particles of the beam, as well as the dissociated pairs, partake of the current amplification of the semiconductor body.

Still further in accordance with a feature of the invention, the semiconductor body junction which is not reversely biased may be formed by a zone of semiconductor material of a conductivity type opposite to that of the central portion. This opposite conductivity type zone is disposed in a space-patterned configuration in juxtaposition with the central portion in a plane intermediate the particle beam source and that central body portion. Thus, in accordance with this additional feature of the invention, need for ancillary beam shields is eliminated. The space-patterned zone of opposite conductivity type accomplishes beam masking functions to endow the beam target structure with signal translating intelligence. At the same time this region enables the semiconductor body to accomplish amplification of both the beam current and the current carriers dissociated in the body by the incidence of the beam.

Still further, the intimacy of association of this space-

patterned region with the central semiconductor body portion yields even further advantage to the switching purposes of the invention. As the signal amplifying abilities of the body are increased and the charged particle beam density is decreased, the delicacy of focusing and beam control thus made possible now makes other sources of signal translating error become of increasing importance. Thus, the aforementioned parallax error becomes more significant. By the integral relationship existing between the beam masking structure and the target semiconductor body itself, any such parallax error is effectively eliminated.

The invention will be more clear and other objects, features and advantages thereof will become apparent from a consideration of the following brief description of an illustrative embodiment thereof taken together with the drawings in which:

FIG. 1 is a partial schematic drawing with selected cross sectional details of an illustrative signal translating system embodying principles of the invention; and

FIG. 2 is an isometric drawing of a structural element which, in accordance with the principles of the invention, may be advantageously employed in the system of FIG. 1.

Referring more particularly to the drawings, in FIG. 1 there is shown a semiconductor body **10**, constructed, for example, of germanium, having a central body portion **12** of one conductivity type material, here n-type. Two zones **14**, **16** of opposite conductivity type material, p-type, are oppositely arranged in juxtaposition with and external to this central body portion and form therewith two rectifying junctions **18**, **20**. These zones advantageously are not arbitrarily thin as shown but conveniently may be of thickness in excess of 1 micron. An electrode **22** is connected to the one zone **14** of p-type material external to the rectifying junction **18** and also to a point **24** of substantially fixed potential.

This zone of p-type material may preferably be established in a semiconductor body of n-type material by alloying to that body a metal contact belonging to the group of materials known in the semiconductor art as acceptor materials. Normally such materials chemically may be classified in the third periodic grouping of elements corresponding to their characteristic three-valence electrons. Aluminum advantageously may be employed for this purpose, as is well known in the art, and as shown in the drawing a thin sheet of aluminum so alloyed forms the electrode **22**.

While the three-valence electron acceptor materials are normally employed with a four-valence electron semiconductor material such as germanium, it is well known that such acceptor materials may be of other atomic structure as well. For example, if a semiconductor body be a compound one composed of two elements respectively lying in the third and fifth periodic grouping, then a suitable acceptor material for forming a rectifying junction may be selected from the second periodic grouping of elements, i.e., from those elements having two-valence electrons. The invention comprehends such variations.

A second electrode **26** is connected to the other semiconductor body zone **16** external to the rectifying junction **20**. One terminal of a load impedance **28** is connected to this electrode and the other load impedance terminal is connected through a biasing potential source, battery **30**, to the point of substantially fixed potential.

The battery **30** is poled to bias reversely the rectifying junction **20**. The load impedance **28**, which is shown illustratively as a resistor, may indeed be any signal utilization apparatus such as, for example, a signal transmission line of the type well known in the art. A charged particle beam source **40**, which advantageously may be a source of electrons such as shown by Sears, includes an accelerating electrode **47** and is associated with an accelerating potential source **48** connected as shown to the accelerating electrode and, conveniently, to the point of substantially fixed potential **24**. This beam source is arranged and the potential source poled to direct the beam electrons in paths substantially intercepting the semiconductor body **10** as indicated by the dotted line.

Horizontal and vertical beam deflecting apparatus **42**, which may correspond to the electrostatic beam deflecting plates of the aforementioned patent to Sears, is arranged in association with the beam source **40**. This beam deflecting apparatus is connected to a source **44** of signals to be translated to direct or modulate the particle beam in a vertical plane, viz., in the plane of the drawing, in response to those signals. The deflecting apparatus also is connected with a timing source **46** to direct the beam in a horizontal plane, i.e., a plane perpendicular to that of the drawing, in response to timing signals from that source. Conveniently this timing signal source may be any one of many such known in the art for moving such a beam by discrete steps in this horizontal plane.

Accepting engineering realities which might make theoretical calculations of academic interest only, each electron from the source **40**, in its incidence upon the central semiconductor body portion **12**, may dissociate in this germanium body approximately one current-carrying electron-hole pair for each 2.5 volts of the potential source **48**. These pairs combine with the current constituted by the incident beam electrons themselves. By virtue of semiconductor body electrode connections to a point of substantially fixed potential as heretofore described, this combined current provides an amplified signal to the load impedance **28** in conformance with well-known common-emitter connected transistor principles. With such connections signal amplification A is achieved and superimposed upon the beam current amplification above-described in accordance with the expression

$$A=\frac{\alpha}{1-\alpha} \qquad (1)$$

where α is the current amplification factor of the semiconductor body.

In accordance with well-known transistor design principles this semiconductor body **10** is constructed to have an amplification factor α close to unity. Hence, noting the relations of Expression 1 above, the signal borne by the charged particle beam from the source **40** is amplified first by the dissociation of current-carrying pairs within the semiconductor body and again enormously in the translation of this already amplified signal through the semiconductor body to the load impedance **28**.

As shown in FIG. 1, the opposite conductivity type zone **14** which forms the nonreversely biased rectifying junction **18** may be disposed substantially in a plane intermediate the central semiconductor body portion **12** and the beam source **40**. Upward deflection of the beam in response to modulating signals from the source **44** directs the charged beam particles to be incident upon this zone of the semiconductor body. Through the direct connection of this zone to the point of substantially fixed potential, the incident electrons and current-carrying dissociated pairs are drained from the semiconductor body through the electrode **22** without passing through the rectifying junction **18** to the load impedance **28**. Thus, in accordance with the invention this zone of opposite conductivity type material, which itself forms a rectifying junction to endow the semiconductor body with transistor amplifying abilities, as noted above, is of a suitable thickness in excess of 1 micron and thus also acts as a shield to render portions of the semiconductor body insensate to the charged electrons from the beam source **40**. This shielding zone being a semiconductor may provide a finite impedance to the flow of this drainage current. This finite impedance might induce some signal in the load impedance as a result of electrons being incident on the opposite conductivity type zone **14**. However, the electrode **22** which forms this zone of opposite conductivity type material advantageously may be itself

interposed, as shown, between the beam and the rectifying junction to provide a drainage path of negligible resistance for any dissociated electron-hole pairs.

In accordance with a feature of the invention as illustrated in FIG. 2, advantage is made of this phenomenon. As shown in FIG. 2, the semiconductor body **10** may be constructed to have the zone **14** arranged in a space-patterned configuration for converting analog beam signal deflections to a binary code. Thus, as shown, the zone **14** of p conductivity type material consists of three horizontally arranged columns A, B and C of p-type material disposed on the central body portion **12**. In the successive columns A, B and C of the major p-type material areas are half the area of each major p-type area of the next preceding column. In the individual columns these major areas are arranged in alternation with exposed central body portion areas of like dimensions as shown. All of the major areas of p conductivity type material are electrically connected to provide an electrically unitary zone of p conductivity type material. The remaining electrical connections are made as shown with like numbers being assigned to corresponding elements in FIG. 2 as in FIG. 1.

The space-patterned zone **14**, as illustrated, may conveniently be constructed on the semiconductor body **10** by alloying an electrode **22** sheet of aluminum foil having a space-patterned configuration, as shown, to the central body portion of the semiconductor body as heretofore described. Alternatively, this space-patterned zone **14** may be produced, for example, by vacuum evaporation and deposition of aluminum particles by techniques well known in the art.

Employed in the system of FIG. 1, the advantageous operation of the semiconductor body as depicted in FIG. 2 is clear. Assume a beam of electrons initially deflected vertically (indicated by arrow V) by the signal source **44** to a position corresponding to that of the dashed line Z—Z. In the "A" and "B" columns this dashed line passes through an exposed area of the semiconductor central body portion **12**. In the "C" column this line passes through the semiconductor body at a position in which the aluminum electrode **22** and the opposite conductivity type zone **14** mask this central body portion. Thus, as the beam is stepped horizontally (indicated by the arrow H) from column "A" to "B" to "C" in response to signals from the timing source **46**, amplified signals are successively derived in the load impedance corresponding to a positioning of the beam in columns "A" and "B."

As the beam is positioned in column "C," the opposite conductivity type zone **14** provides effective masking for the beam and no signal appears in the load impedance. Thus, the vertical position of the beam is represented in the load impedance successively as Signal, Signal, No

Signal conditions in the load impedance in relation to signals from the horizontally deflecting timing source. Such time arranged signals constitute a time code, e.g., a binary code representation of the amplitude of the vertical beam deflection. This particular signal may, for example, represent in the binary code an amplitude of 6.

Thus, the analog vertical deflection amplitude signal of the beam from the source **40** is converted to a binary representation of that signal by a structure in accordance with the invention in which a portion, the zone **14**, of a semiconductor amplifying element accomplishes not only its normal transistor amplifying functions, but, as well, in cooperation with the timing source and signal source, endows the amplifying semiconductor body with an intelligence to transform the analog signal to an entirely different form as this signal is translated and amplified.

It will be readily apparent to those skilled in the art that many other variations of this illustrative embodiment may be achieved within the spirit and scope of the invention.

What is claimed is:

1. Apparatus for translating a signal from a signal source to a load impedance, said apparatus comprising a source of a beam of charged particles, a semiconductor body disposed to have a front surface in target relation with the particle source, the semiconductor body comprising a first zone of one conductivity type forming part of said front surface, a second zone of opposite conductivity type forming the back surface, a third zone of said opposite conductivity type forming the remaining part of said front surface, low resistance electrodes contacting said second and third zones, said first zone of one conductivity type being free of any electrodes, means for directing a beam from said source upon said front surface, means for connecting said third zone electrode to a point of substantially fixed potential, said load impedance being connected between said second zone electrode and said point of fixed potential, and means for biasing the PN junction between said first and second zones in the reverse direction.

2. Apparatus in accordance with claim 1 in which said third zone comprises an array of spaced apart portions, said portions being connected in common electrically.

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