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**CONTROLLED-BREAKOVER BIDIRECTIONAL
SEMICONDUCTOR SWITCH**

This invention relates to bidirectional
5 semiconductor switches such as TRIAC switches.

Bidirectional semiconductor switching devices of
the gate-controlled type for controlling currents are well
known. In particular, one type of silicon-controlled
rectifier comprises a silicon semiconductor body of
10 five zones of alternating conductivity type from one major
surface to the other. The gate or control contact is made
to a zone adjacent to a terminal zone. Conduction in
either direction is enabled, depending on the respective
polarity of the voltage at the terminal zones when a
15 trigger voltage is applied to the gate zone.

Ordinarily, the bidirectional switching device
just described is triggered by separately generated gate
voltages applied from external sources. For certain
applications, it would be useful to provide a two-terminal
20 device responsive to voltages within a relatively narrow
range to switch the element from a high impedance OFF
condition to a low impedance ON condition. It would be
desirable that such a device should be responsive to
voltages of either polarity.

25 According to the present invention there is
provided a semiconductor switching device comprising

a body of semiconductor material including a five-zone
bidirectional switching element comprising a series of
five zones of alternating conductivity type and a three-
zone bidirectional voltage-sensitive breakdown element
5 comprising a series of three zones of alternating conductivity
type, the zones of the three-zone element having a common
surface coincident with a first major surface of the body
and comprising a first terminal zone, an intermediate zone
and a second terminal zone, the first terminal zone being
10 encompassed by the intermediate zone and the intermediate
zone being encompassed by the second terminal zone, the
second terminal zone of the three-zone element being
common with one of the zones of the five-zone element,
the common zone acting as a gating element to trigger
15 conduction in either direction in the five-zone element.

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A voltage of either polarity applied to the three-zone element in excess of the breakdown voltage of the three-zone configuration, results in conduction therethrough, which in turn triggers the five-zone element into conduction.

The two p-n junctions of the three-zone transistor-like configuration are preferably of the Zener type, exhibiting sharp voltage breakdown characteristics. If the two p-n junctions are formed with the appropriate spacing and impurity doping, they will exhibit the gain characteristics of a transistor and will carry current in the sustaining state after breakdown, which current then will trigger the five-zone element into conduction.

An application of devices in accordance with the invention is to function as a telephone line termination unit in both tip and ring, which will break down precisely and conduct when subjected to operating voltages in the range, typically of greater than about 12 to 22 volts. In one type of testing mode to determine from a central office whether a shorting fault is located in the customer's premises or elsewhere, a relatively high voltage, typically 100 volts in series with a large resistor, is applied to the line. If the line is satisfactory as far as the termination unit, the unit will switch to the ON state and energize a capacitor-resistor circuit connected across the termination unit. If the holding current of the five-zone element is above the maximum current supplied from the central office, then the capacitor-resistor circuit in combination with the five-zone element alternately charges and discharges, thus exhibiting a distinctive characteristic at the test

location. This indicates that the line is satisfactory as far as the termination unit, and therefore any fault is in the customer premises equipment.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings of which:-

FIGS. 1, 4 and 5 are sectional views of various devices according to the invention.

FIGS. 2 and 3 are equivalent circuits to illustrate aspects of the performance of the devices of FIGS. 1, 4 and 5, and

FIG. 6 is a graphical representation of the current-voltage characteristic of an exemplary device according to the invention.

Referring to FIG. 1, the device 10 is similar to bidirectional semiconductor switching devices of the gate-controlled type known in the prior art, with the exception, however, that a separate gate electrode is not provided, and the device illustrated is a two-terminal element. More specifically, the device 10 is a body of single crystal silicon semiconductor material having a first major surface 11 and a second major surface 12. For purposes of explanation, the portion to the right of the centre line 50 is referred to as the first portion and to the left, the second portion. In the first portion and between the major surfaces 11 and 12, there are five zones of alternating conductivity type. At the first major surface, there is shown first terminal zone 17 of n-type conductivity and p-type zone 13 adjacent thereto of p-type conductivity. At the second major surface, there is shown the second terminal zone 18 and p-type zone 15 adjacent thereto. The fifth zone is the intermediate n-type zone 14, which is generally more lightly doped than the other zones, particularly the terminal n-type zones. A first main terminal (MT1) provided by a metal film electrode 21 makes ohmic contact to both terminal zone 17 and adjacent zone 13. A second main terminal (MT 2) makes ohmic contact to the second terminal zone 18 and the zone 15

adjacent thereto. Terminal MT2 generally is applied to the entire second major surface of the device. A p-type conductivity zone 16, which is relatively highly doped, provides a protective enclosure at the edges of the body 10 and, as will be more fully explained hereinafter, provides a conduction path through the body.

The first portion of the device, as thus described, constitutes a symmetrical or bidirectional switching device when provided with suitable triggering input to the zone 13. As is known, the injection of, in this case, electrons from a suitable source into the zone 13 produces currents which, in conjunction with a voltage applied across the main terminals MT1 and MT2, result in the forward biasing of the p-n junctions between zones 13 and 14, and 14 and 15, sufficient to enable conduction through the first portion of the device. The direction of conduction will depend on the polarity of the voltage applied across the main terminals and may occur either by way of MT1 through p-type zone 13, n-type zone 14, p-type zone 15, n-type zone 18, to terminal MT2; or, from MT1 through n-type zone 17, p-type zone 13, n-type zone 14, p-type zone 15, and terminal MT2. Thus, conduction is enabled in either direction in a four-region device turned ON by a triggering voltage applied to a gate zone adjacent one terminal zone.

Triggering action is provided by the structure to the left of the centre line 50, referred to as the second portion of the body. In this second portion, there are three significant zones 13, 19 and 20 of alternating conductivity type defining a pair of PN junctions. One of the three zones is p-type conductivity zone 13, which is common also to the first portion of the body. Within p-type zone 13 and wholly encompassed thereby is n-type zone 19, and likewise within zone 19 and wholly encompassed thereby is p-type zone 20. The three zones of pnp configuration each have a common surface coincident with the first major surface 11.

An interconnecting element 23, typically a metal

film, is in ohmic contact with p-type zone 20 and heavily doped p-type enclosing zone 16. The element 23 is insulated from other portions of the body by the dielectric film 24. As previously noted, zone 16 has a surface common to the second major surface and in contact with the second main terminal constituted by the metal film 22. Thus, p-type zone 20 is directly connected to MT2. The p-n junctions defined by the successive zones 20, 19 and 13 are tailored to function as breakdown diodes of the Zener type so that the application of a particular voltage of either polarity will produce breakdown of whichever of the pair of junctions is reverse biased, thereby resulting in conduction through the pnp configuration. Note that the voltage is applied across MT1 and MT2, since as MT1 is directly connected to p-type zone 13 and MT2 is directly connected to p-type zone 20.

The circuit equivalent of the device of FIG. 1 is illustrated in FIGS. 2 and 3. In FIG. 2, the symbol 25 represents a gate-controlled semiconductor switch of the TRIAC type, having main terminals MT1 and MT2 and a gate connection connected from the gate of device 25 through a pair of oppositely poled Zener diodes 26 and 27 connected to MT2. Referring to FIG. 3, the pair of Zener diodes are shown as a pnp transistor 29 connected in the trigger circuit of the bidirectional semiconductor switch 28. More particularly, the transistor function is achieved by providing an appropriate spacing for the n-type conductivity zone 19 which, in effect, functions as the base zone of the transistor. Thus, there is provided a compact unitary device in which one portion contains a relatively high voltage bidirectional switching element composed of five conductivity-type zones and a second portion contains a bidirectional voltage-sensitive breakdown element having precise characteristics for producing the triggering effect in the first portion. In particular, the junctions between the zones 13, 19 and 20 are designed to break down and conduct at voltages typically in the range of from 12 to 22 volts. Telephone line operating voltages

are typically about 48 volts, sufficient to break down a pair of devices, installed in both tip and ring, at the interface between the entrance line and the customer's premises. Thus, the device conducts at operating voltages enabling normal use of the telephone service. When a shorting fault occurs, a determination can be made as to whether the difficulty lies within the service provider's apparatus or on the customer's premises by applying to the line a relatively high voltage, such as about 100 volts. For example, if a shorting fault is present in the line before it reaches the maintenance termination unit, the line may show one form of response. If the difficulty is on the customer's premises, associated circuitry, in combination with the semiconductor device, may exhibit a different distinctive response.

The device illustrated in FIG. 1 is readily fabricated using well-known semiconductor fabrication techniques, including photolithographic processing for masking and impurity introduction using ion implantation and solid state diffusion. Processes of the type generally employed are set forth in U.S. Patent No. 4,066,483, granted January 3, 1978, to F.A. D'Altroy et al.

The device shown in FIG. 4 is a variation of the device of FIG. 1 in which the first terminal zone 40 of the second portion is offset within the intermediate zone 39 in a direction away from the first portion of the device. The device of FIG. 4 is otherwise similar to the device of FIG. 1, having first major surface 31 and second major surface 32, terminal zones 37 and 38 of the first portion, and terminal-adjacent zones 33 and 35, along with intermediate zone 34. Main terminal MT1 is formed by metal electrode 41 and main terminal MT2 by film electrode 42. Highly doped p-type zone 36 provides edge protection and conduction as previously noted. The offset of zone 40 enhances the triggering action by the three-zone voltage-sensitive element.

The device of FIG. 5, having the voltage-sensitive element composed of a lateral transistor

configuration, is otherwise similar to that described in FIGS. 1 and 4. P-type zone 71 constitutes the first terminal zone of the second portion of the device. P-type zones 70 and 72 may be separately formed zones or may be composed of a single annular configuration or may be a series of spaced-apart zones. The zones 70 and 72 constitute a highly doped section of the p-type second terminal zone of the second portion. Further, the zones 70 and 72 are located at the boundary, that is, the p-n junction, between the intermediate zone 69 and the p-type second terminal zone 63 and at the first major surface 61. In this device, fabrication is simplified from the standpoint of achieving a precise basewidth, as defined by the spacing between the p^+ zone 71 and the zones 70-72, which enables transistor current gain and the sustaining of conduction as previously described.

FIG. 6 illustrates the current-voltage characteristic of this type of device, in which the application of increasing voltage in either direction results in little increasing current until a point is reached at which there is sufficient rise in current to produce triggering, at which point the voltage drops and current rises with little increase in voltage.

When the triggering element behaves like a pnp transistor rather than simply a pair of oppositely poled breakdown diodes, the characteristic shown in FIG. 6 may be expected to display a negative resistance characteristic immediately following the inception of conduction in the triggering element. That is, the curve will break back toward the origin as soon as the current begins to increase. This response is advantageous when in a testing mode for assuring establishment of the ON state of the bidirectional switching element when the shorting fault is highly resistive.

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CLAIMS

1. A semiconductor switching device comprising
a body of semiconductor material including a five-zone
bidirectional switching element comprising a series of
5 five zones of alternating conductivity type and a three-zone
bidirectional voltage-sensitive breakdown element comprising
a series of three zones of alternating conductivity type,
the zones of the three-zone element having a common surface
coincident with a first major surface of the body and
10 comprising a first terminal zone, an intermediate zone
and a second terminal zone, the first terminal zone being
encompassed by the intermediate zone and the intermediate
zone being encompassed by the second terminal zone, the
second terminal zone of the three zone element being common
15 with one of the zones of the five-zone element, the common
zone acting as a gating element to trigger conduction in
either direction in the five zone element.

2. A device as claimed in claim 1 wherein the
five-zone element extends from a first major surface of
20 the body to a second major surface of the body, including
a first terminal on the first major surface in ohmic
contact with one terminal zone of the five-zone element and
with the zone adjacent the said one terminal zone and a
second terminal on the second major surface in ohmic
25 contact with the other terminal zone of the five-zone
element and with the zone adjacent the said other terminal
zone.

3. A device as claimed in claim 2 wherein the
second terminal zone of the three-zone element is common
30 with the said zone adjacent the one terminal zone of the



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five-zone element.

4. A device as claimed in claim 3 wherein conductive means extend between the first terminal zone of the three-zone element and the second terminal.

5 5. A device as claimed in claim 4 wherein the said conductive means includes an interconnecting element on the first major surface and a zone of high conductivity in the body extending from the first major surface to the second major surface.

10 6. A device as claimed in claim 5 wherein the interconnecting element is in ohmic contact with the first terminal zone of the three-zone element.

7. A device as claimed in claim 5 or claim 6 wherein the zone of high conductivity has a surface
15 coincident with the second major surface and the second terminal makes ohmic contact to the said coincident surface.

8. A device as claimed in any of claims 3 to 7 wherein the first terminal zone of the three-element
20 zone is offset within the intermediate zone by which it is encompassed in a direction away from the said one terminal zone of the five-zone element.

9. A device as claimed in any of claims 3 to 7 wherein the second terminal zone of the three-terminal
25 zone includes a section of relatively higher conductivity at the intersection of the first major surface with the boundary between the intermediate zone and the second terminal zone of the three-terminal zone.

10. A device substantially as herein
30 described with reference to FIG. 1, 4 or 5 of the accompanying drawings.

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