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(54) SEMICONDUCTOR SWITCHING DEVICE

(71) We, RCA CORPORATION (formerly Radio Corporation of America), a corporation organised under the law of the State of Delaware, United States of America, of 30, Rockefeller Plaza, City and State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a bidirectional current conducting switching device.

The technical advance of the art is as follows:

The class of thyristor known as a controlled rectifier is a four-layer P-N-P-N (or N-P-N-P) semiconductor switch having anode, cathode, and gate electrodes. It is usually fabricated from silicon. In its normal state, the silicon controlled rectifier (SCR) is non-conductive until an appropriate voltage or current pulse is applied to the gate electrode, at which point current flows from the anode to cathode and delivers power to a load circuit. If the SCR is reverse biased, it is non-conductive and cannot be turned on by a gating signal. Once conduction starts, the gate loses control and current flows from the anode to the cathode until it drops below a certain low value (called the holding current), at which point the SCR is off and the gate electrode regains control. The SCR is thus a solid state device capable of performing the circuit function of a thyratron tube in many electronic applications.

In some of these applications, such as, for example, certain inverter circuits, automobile ignition systems, and horizontal deflection circuits for television receivers, it is necessary to connect a separate rectifier diode in parallel with the SCR. The anode of the rectifier diode is connected to the SCR cathode and the cathode of the rectifier is connected to the SCR anode. Thus, the rectifier will be forward biased and current will flow through it when the SCR is reverse biased, i.e., when its cathode is positive with respect of its anode. For reasons of economy and ease of handling, it would be preferable if the circuit function of the SCR and the associated rectifier diode could be combined in a single device so that instead of requiring two devices and five electrical connections, one device and three electrical connections are all that would be needed.

According to the invention we provide a bidirectional current conducting switching device comprising a semiconductive body including four layers which alternate in conductivity type to form a plurality of PN junctions therein; a first electrode in contact with an external layer of said body and a first exposed surface of a first intermediate layer adjacent said external layer; a gate electrode in contact with said first intermediate layer; and a second electrode in contact with the other external layer of said body and a second exposed surface of a second intermediate layer adjacent said other external layer; said four layers and said first, gate, and second electrodes providing a controlled rectifier which conducts current in one direction; and said intermediate layers and said first and second electrodes providing a diode rectifier which conducts current in an opposite direction to said one direction when said controlled rectifier is non-conductive, characterized in that said second intermediate layer comprises first and second portions, said second portion being of greater conductivity than said first portion and said first portion having a surface constituting said second exposed surface forming a peripheral border to said other external layer.

An embodiment of the invention will now be described with reference to the accompanying drawings in which:—

Figure 1 is a schematic circuit diagram of a portion of the horizontal deflection circuit of a television receiver which illustrates an application of the present invention;

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Figures 2a to 2f are cross-sectional views of a semi-conductor device embodying the invention during various stages of its manufacture;

Figure 3 is a perspective view, in section, of a semiconductor device embodying the invention;

Figure 4 is an equivalent schematic circuit diagram of a device of the type illustrated in Figure 3; and

Figure 5 is a voltage versus current characteristic curve for a device of the type illustrated in Figure 3.

Referring now to the drawing, and in particular to Figure 1, there is shown a horizontal deflection circuit of a television receiver in which the invention may be used. The circuit includes a first and a second bidirectionally conductive switching means 12 and 14. The switching device of the invention would be suitable for use as either the switching means 12 or 14, for example. Each of the switching means 12 and 14 of the horizontal deflection circuit comprises the combination of a controlled rectifier, in each case a silicon controlled rectifier (SCR), and a diode arranged to conduct current in a direction opposite to the direction of conduction of the associated SCR. Thus, the switching means 12 includes an SCR 16 and a diode 18, the cathode of which is connected to the anode of the SCR 16 and the anode of which is connected to the cathode of the SCR 16. Similarly, the anode of a diode 22 is connected to the cathode of an SCR 20 in the switching means 14 and the cathode of the diode 22 is connected to the anode of the SCR 20.

The bidirectional conductive switching means 12 and 14 are arranged in the deflection circuit so as to provide a saw-tooth current wave through a horizontal deflection winding 24 of a television kinescope 26 during the trace portion of the horizontal deflection cycle. To this end, the diode 22 conducts current during the first-half of the trace portion of the deflection cycle and the SCR 20 conducts current during the remainder of the trace portion of the deflection cycle. During retrace, both the diode 20 and the SCR 22 are in the non-conducting "off" condition.

To initiate the retrace portion of the cycle, the bidirectional switching means 12 is rendered conductive by the application of a horizontal output pulse to the gate electrode of the SCR 16. During retrace the deflection current reverses, rendering the SCR 16 non-conductive. During the latter portion of the retrace cycle, while SCR 16 is off, current flows through the diode 18.

Thus, in order to operate for their intended purpose, each of the bidirectionally conductive switching means 12 and 14 requires that an oppositely poled diode be connected in parallel with the SCR to permit the reverse flow of current during approximately one-half both the trace and retrace portion of the deflection cycle. This invention is directed to a device in which bidirectional current flow of this type is achieved in a unitary structure. Thus, devices embodying the invention are suitable for use, for example, in horizontal deflection circuits of the type described or in any other switching circuit where the flow of reverse current is desired when the bias reverses, i.e., when the SCR is reverse biased and non-conducting.

Referring now to Figures 2a—2f, the starting material for devices embodying the invention is a body 28 of a crystalline semiconductive material, preferably silicon. The precise shape, composition, conductivity type, and electrical resistivity of the semiconductive body 28 is not critical. In this particular example, the body 28 is of N conductivity type silicon having a resistivity of about 20 ohm-cm. In practice, a large number of units would be simultaneously formed on the body 28. To simplify the explanation of the invention, however, the fabrication of only a single device is illustrated in Figures 2a—2f.

Insulating layers 30 and 32 (Figure 2b) of silicon dioxide is next grown on opposite surfaces of the body 28 by, for example, heating the body 28 for about three hours in an ambient of steam. The next step in the process (Figure 2c) is to remove the insulating layer 30 completely from the top surface of the body 28 and to remove a portion of the insulating layer 32 from the bottom surface of the body 28 to form a window 33. These layers may be removed by any convenient well-known method such as, for example, by using photolithographic and etching techniques.

Following this step, a source, such as boron nitride, of P type dopant is applied to the exposed portions of both the upper and bottom surfaces of the body 28. The body is then heated at approximately 850°C for one-half hour to diffuse boron into the body 28. P type layers 34 and 36 are thus formed within the body 28 across its entire top surface and under the area defined by the window 33, respectively. The boron source is then stripped off the top surface and the silicon body 28 is heated at around 1300°C in an oxidizing atmosphere for approximately 20 hours, diffusing boron left at the surface into the body under the opening 33 and converting the area 36 into a region of P+ conductivity.

Next, a layer 38 (Figure 2e) of insulating material, such as silicon dioxide, is grown or deposited on the top surface of the semiconductive body and an opening 40 is defined in this layer. At the same time, an insulating layer 44 is grown or deposited on the bottom

surface and subsequently removed from all portions of this surface except in the area over the P+ region 36. The semiconductive body 28 is then heated in the vapors of an N doping source such as phosphorus pentoxide for about 2 hours at approximately 1265°C to form a diffused annular N+ region 46 under the opening 40 and a second diffused annular N+ region 48 which surrounds the P+ region 36 on the bottom surface of the semiconductive body 28.

The silicon dioxide layers 38 and 44 are then removed and a new insulating layer 50 (Figure 2f) is grown or deposited on the top surface of the semiconductive body 28. Using photolithographic and etching techniques, an annular opening 51 is made in this layer through which an annular moat 53 is etched into the semiconductive body. Following this step, the insulating layer 50 is removed and a conductive metal layer 55 such as, for example, nickel is electroplated or otherwise deposited on the top surface of the device. Copper electrodes 56 and 58 are soldered to this metal layer 55 to provide an SCR gate electrode 56 and an SCR cathode 58. The bottom surface of the device is soldered or brazed to a metallic surface 60 which would, for example, be a surface of the device enclosure or package. This surface thus serves as the SCR anode of the completed device.

The completed device is thus similar in construction to a conventional SCR; one important difference being that the region 61, which is the remaining N type portion of the original body 28, is connected or shorted to the SCR anode 60 of the device. In the present example, this is accomplished by connecting the N region 61 to the SCR anode 60 through the highly doped annular N+ region 48. The completed device is electrically equivalent to either the switch 12 or the switch 14 of the Figure 1 circuit or the circuit of Figure 4, where a diode rectifier 62 is connected in parallel with an SCR 64 and is poled for forward conduction in a direction opposite to that of the SCR 64. In the actual device of Figure 3, the periphery serves as a diode rectifier, such as the diode rectifier 62 of Figure 4. That is, a diode junction is provided between the P region 34, which serves as the anode of the diode rectifier, and the N region 61 which, in combination with the highly conductive N+ region 48, serves as the cathode of the diode rectifier. The SCR is a N+PNP+ structure having an anode 60, a cathode 58, and a gate 56.

When a positive bias is applied to the cathode 61 of the peripheral diode and a negative bias is applied to the diode anode 34, the diode rectifier will be biased in the reverse, non-conducting direction and will block the flow of current. Under these conditions, the bias voltage on the SCR is in the forward direction, that is the SCR cathode 58 is negative and the SCR anode 60 is positive. Thus, the SCR conducts current in a direction from the SCR anode 60 to the SCR cathode 58. When a bias voltage of an opposite polarity is applied, that is when the cathode 61 of the peripheral diode is negative and the diode anode 34 is positive, the SCR is biased in the reverse, non-conducting direction and will block the flow of current. The peripheral diode is biased, under these conditions, to conduct current in the forward direction. Thus, during periods when the SCR is biased off, the peripheral diode, defined by the P+N regions 34 and 61, which lie between two ohmic contacts, is forward biased and conducts current, thus permitting the flow of reverse current with a single device.

Under forward bias conditions, the SCR can be triggered into conduction by the application of positive voltage pulses to the SCR gate electrode 56. When positive pulses are applied to the SCR gate 56, hole current flows from the gate contact, through the P base region 34 and to the periphery of the device where the SCR cathode 58 makes contact to the P region 34. The lateral flow of current in the P region 34 will cause a voltage drop which is applied to the N+ region 46, forward biasing the N+ region 46 in the center near the SCR gate contact 56. Thus, the N+ region 46 injects electrons. Some of these electrons diffuse across the P region 34 and into the depletion region of the junction between the P region 34 and the N region 61, which sweeps them across the junction and into the N region 61. Some of these electrons will then flow laterally through the N and N+ regions 61 and 48 and out to the anode 60 of the SCR. The voltage drop due to this lateral current puts a forward bias on the P+ region 36 near the center so that it begins to inject holes into the N region 61. Some of these holes diffuse across the N region 61 into the P region 34, which increases the forward bias on the N+ region 46 and causes it to inject more electrons. In this way, the SCR portion of the device becomes highly conductive.

The electrical characteristics of a device constructed in accordance with the foregoing are illustrated in Figure 5, where the anode-to-cathode current (ordinate) is plotted against the voltage (abscissa) between the anode and the cathode. When the voltage between the anode and the cathode is in the reverse non-conducting direction, the SCR portion of the device is non-conductive, but the peripheral rectifying diode is biased in the forward direction and conducts current. This is shown by the portion 66 of the current-voltage curve. When the polarity of the applied bias voltage reverses to forward bias the SCR, a small

leakage current will flow. As the forward bias voltage is increased, a voltage point 68 is reached at which the forward current increases rapidly. When the forward current exceeds a critical value, the voltage across the SCR reverts back to a low value. At this point, the SCR is in the "on" condition and the forward current increases rapidly with slight increases in the forward bias voltage. This is shown by the portion 70 of the current-voltage characteristic curve.

Devices embodying the invention thus incorporate, in one semiconductor device, the desirable operating characteristics of an SCR and have the added feature of being capable of supporting current flow in the reverse direction. These devices are therefore suitable for electronic applications requiring an SCR together with a separate, parallel-connected diode rectifier.

WHAT WE CLAIM IS:—

1. A bidirectional current conducting switching device comprising a semiconductive body including four layers which alternate in conductivity type to form a plurality of PN junctions therein; a first electrode in contact with an external layer of said body and a first exposed surface of a first intermediate layer adjacent said external layer; a gate electrode in contact with said first intermediate layer; and a second electrode in contact with the other external layer of said body and a second exposed surface of a second intermediate layer adjacent said other external layer; said four layers and said first, gate, and second electrodes providing a controlled rectifier which conducts current in one direction; and said intermediate layers and said first and second electrodes providing a diode rectifier which conducts current in an opposite direction to said one direction when said controlled rectifier is non-conductive, the second intermediate layer comprising first and second portions, said second portion being of greater conductivity than said first portion and said second portion having a surface constituting said second exposed surface forming a peripheral border to said other external layer.

2. A bidirectional current conducting switching device as claimed in claim 1, wherein said first electrode constitutes a cathode for said controlled rectifier and an anode for said diode rectifier, and said second electrode constitutes an anode for said controlled rectifier and a cathode for said diode rectifier.

3. A bidirectional current conducting switching device substantially as described with reference to the accompanying drawings.

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