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(54) Transient absorption semiconductor device for voltage surge protection

(57) A transient absorption semiconductor device comprises a thin planar semiconductor body 1 of one conductivity type having regions 2,3 of opposite conductivity type diffused into opposite surfaces thereof so as to define relatively closely spaced rectifying junctions 5,6 which interact with one another when the device is subjected to an overvoltage causing the reverse biased one of the junctions to breakdown from a low to a relatively high conductivity state. With an increase in the magnitude of the current flowing in the device, the potential difference developed across the device decreases from the breakdown voltage but does not decrease below a set non-zero voltage. Also disclosed is a dual device with greater power handling capabilities comprising two such devices connected in series.

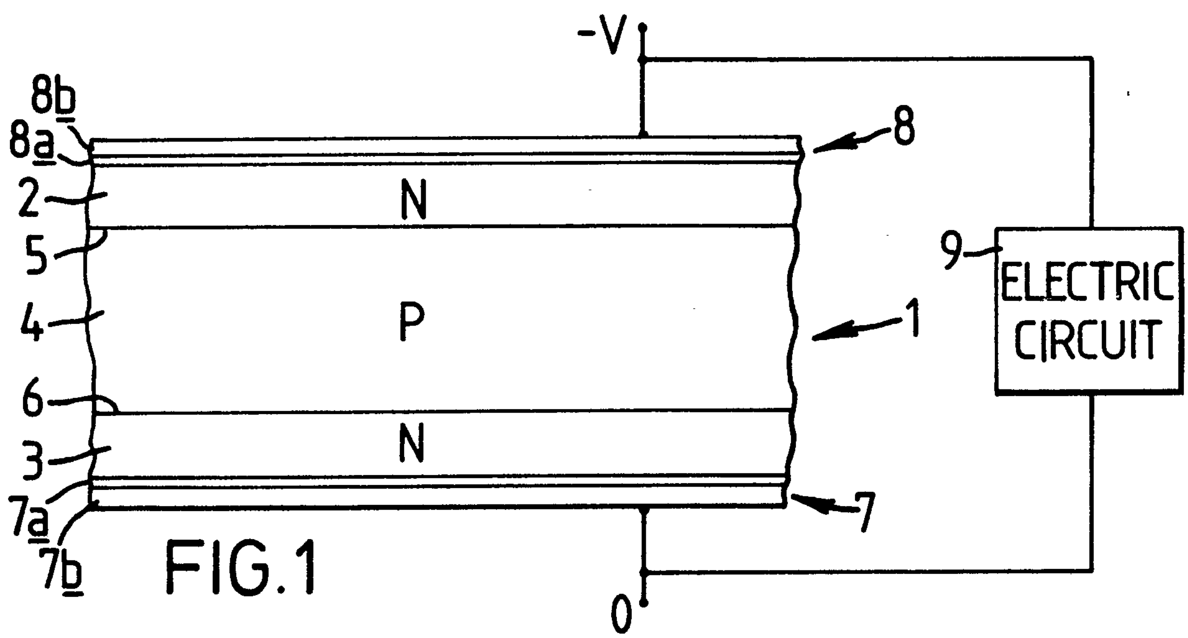

FIG.1

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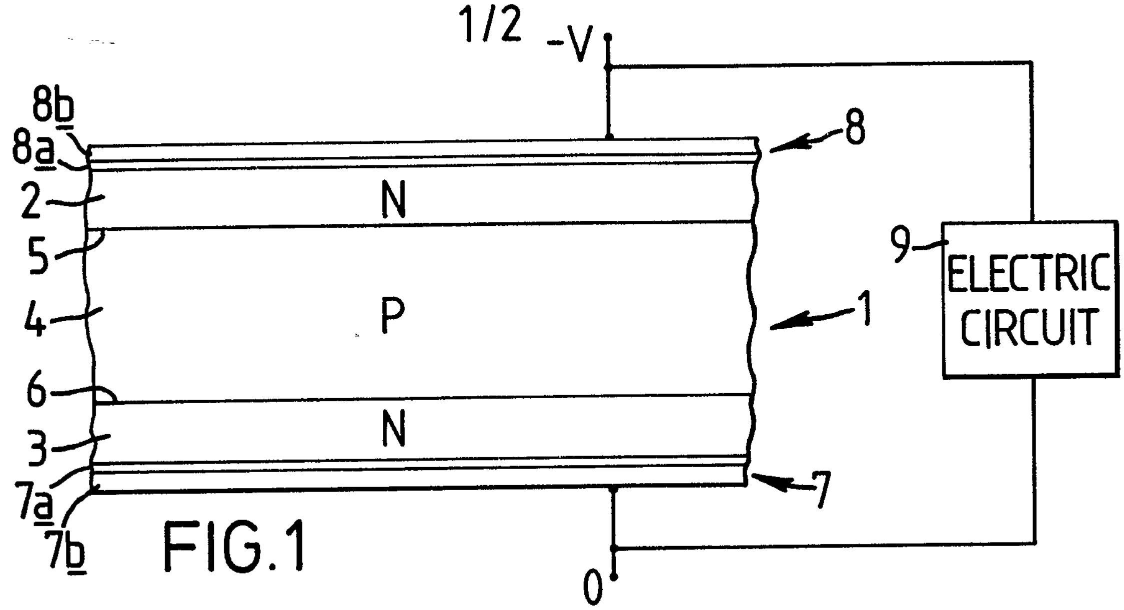
-V
8b
8a
8
2
N
5
9
ELECTRIC CIRCUIT
4
P
1
6
N
3
7a
7
7b
0

FIG.1

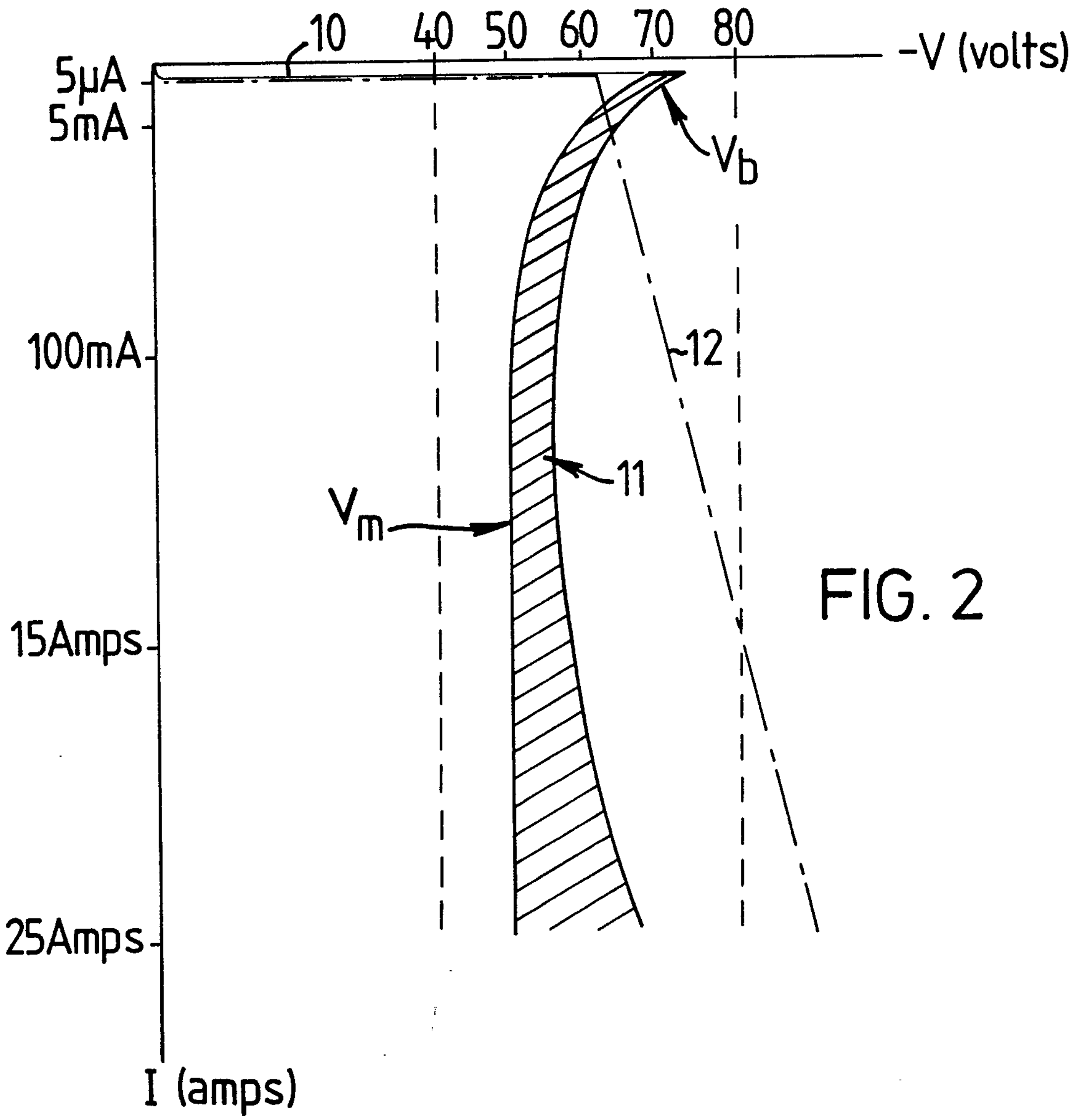
10
40
50
60
70
80
-V (volts)
5µA
5mA
V_b
100mA
12
11
V_m
15Amps
25Amps
I (amps)

FIG. 2

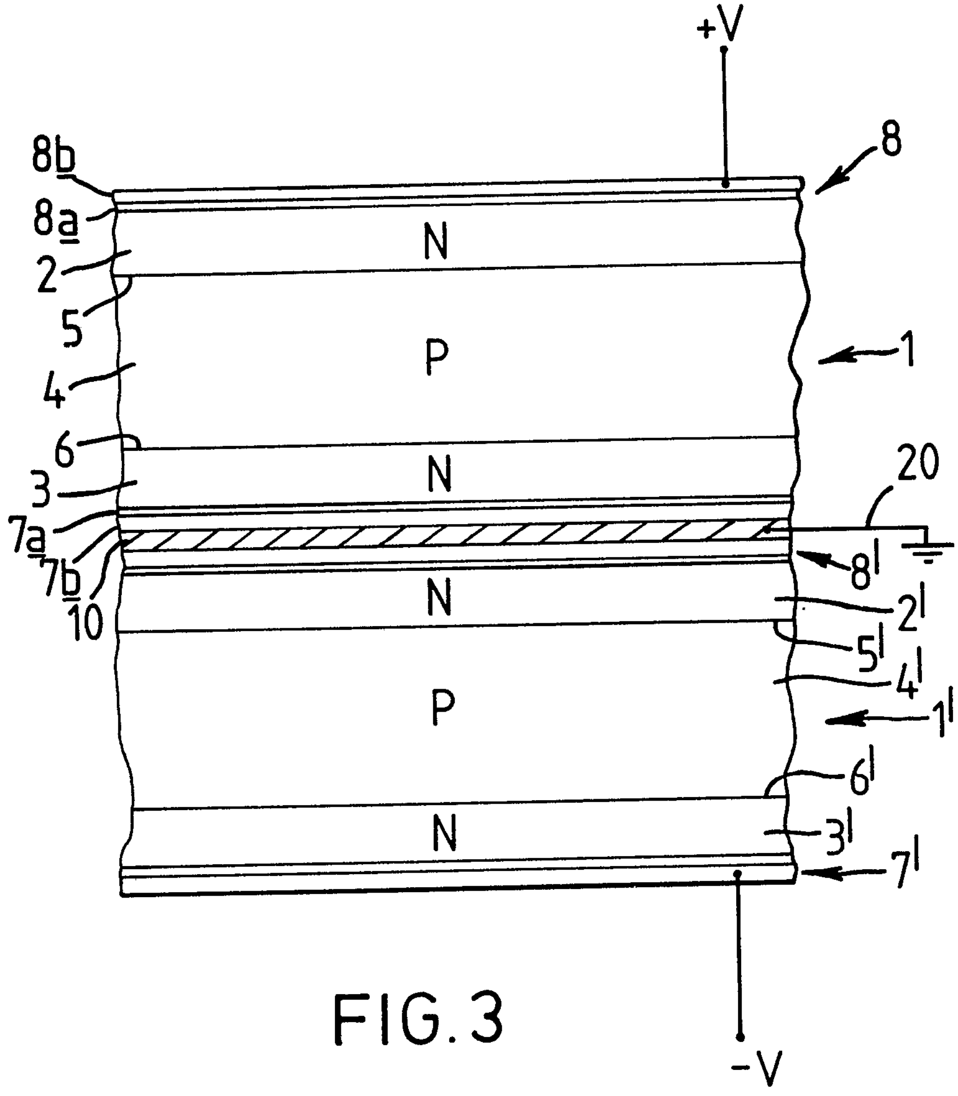

FIG.3

SPECIFICATION

Transient absorption semiconductor device

This invention relates to a transient absorption semiconductor device, for presenting a relatively high impedance over a given range of applied voltage and for presenting a low impedance in response to transient voltage excursions from the given range, the device having particular application as a protection device in an electrical circuit, for protecting the circuit by selectively conducting transient surges in current flowing in the circuit.

It is known that a PN junction in a semiconductor body can be used to protect an electrical circuit from transient voltage surges. The PN junction is connected across a voltage supply to the circuit such as to be reverse biased. The breakdown voltage of the reverse biased junction is selected to be somewhat greater than the voltage normally developed by the supply. Thus in normal use, the junction does not conduct substantially but in the event of a transient voltage surge which results in the supply voltage exceeding the breakdown voltage, the reverse biased junction breaks down and conducts the current surge associated with the voltage surge, so as to protect the circuit from the surge. The breakdown voltage is typically in the range 2–1000V the value thereof being selected for the junction concerned by conrol of the doping levels utilised in manufacture of the junction. For higher voltages in the aforementioned range of breakdown voltages the breakdown occurs by virtue of the Avalanche effect whereas at lower voltages the Zener effect may predominate.

Typically the current flowing in the reverse biased junction prior to breakdown is of the order of 1–10μA whereas after breakdown, heavy current surges with peak currents of 25 amps or more may flow. The junction does exhibit a finite impedance upon breakdown and the voltage across the broken down junction increases steadily with increased current flow through the junction. Thus, heavy current surges cause heating of the junction and this limits the surge current handling capacity of the device. The current handling capacity can be increased by mounting the junction in a heat dissipating capsule but with the disadvantage of increasing the bulk of the device and making it unsuitable for direct mounting on a printed circuit board. Also, because of the finite impedance of the broken down junction, the voltage across the device rises above the voltage occurring at breakdown as the current increases and the voltage may rise to a level which is unsafe for the circuit being protected.

For protecting an a.c. circuit, it is known to connect two such transient absorption devices in series with their polarities arranged in opposite senses, so that the PN junctions are respectively reverse biased by positive and negative going portions of the a.c. waveform. The junctions thus respectively provide surge protection for positive and negative going voltage transients. It is known also to integrate the two junctions into a single package, either by electrically connecting together two PN junctions, or by taking a P type substrate and doping N type regions into opposite surfaces thereof, so as to form the two PN junctions. On breakdown of either of the junctions, the device exhibits the aforementioned characteristic of increased high voltage with increasing surge current and thus suffers from the disadvantages hereinbefore mentioned.

The present invention provides an improved transient absorption semiconductor device in which the aforementioned disadvantages are at least substantially reduced.

According to the present invention there is provided a transient absorption semiconductor device comprising a body of semiconductor material including a region of a first conductivity type disposed between regions of opposite conductivity type so as to define first and second spaced apart semiconductor rectifying junctions, first and second electrodes so arranged that when a potential difference is applied thereto one of said junctions is forward biased and the other of the junctions is reverse biased, the junctions being disposed to interact in such a manner that upon breakdown of the reverse biased junction from a relatively low conductivity state to a relatively high conductivity state and with an increase in the magnitude of the current flowing through the device, the magnitude of the potential difference developed across the electrodes decreases from that which causes said breakdown but does not decrease to a value less than a given non-zero value.

Those skilled in the art will readily be able to determine from the following explanations and by routine trial and experiment suitable junction configurations and doping levels which produce this decrease in voltage upon breakdown of the reverse biased junction. We have found by experiment that the junctions should be placed closer to one another than in a comparable example of the aforementioned prior art two junction a.c. device and we postulate that this results in majority carriers from the forward biased junction being swept into the reverse biased junction, in greater numbers with increased surge current, so as to modify the characteristics of the broken down junction and produce the decreasing voltage characteristic which characterizes the present invention.

The device according to the invention has the advantage that because its voltage decreases to a given level after breakdown, the heat generated in the device by a surge current is reduced and the surge current handling capability of the device is correspondingly greater than in a comparable example of the aforementioned prior art devices. The device further has the significant and substantial advantage that when coupled in parallel with a circuit for protecting the same from overvoltage surges, the fact that the voltage developed across the device decreases below the device breakdown voltage (which by definition must be below the maximum voltage sustainable by the circuit which the device protects) when the device operates to divert a surge from the protected circuit ensures that throughout the duration of the surge the protected circuit is never subjected to a voltage which is even as high as the device breakdown voltage; in the prior art devices, the voltage developed across the device during a surge rises above the device breakdown voltage and, unless the device breakdown voltage is set at a level significantly lower than the maximum voltage sustainable by the circuit, can exceed the safe circuit voltage. The device according to the invention thus provides a much more precise and definable protective function than has hitherto been obtainable with prior art devices.

Whilst, as will hereinafter be discussed, variation of one or more of the manufacturing parameters of the device according to the invention enables devices to be manufactured consistently and reliably with breakdown voltages within a relatively wide range and up to relatively high values of the order of 150 to 200 volts for example, for applications in the higher voltage areas the invention further proposes, rather than the provision of a single device, to couple together in series two or more devices each of a lower breakdown voltage rating. The resultant composite device has a breakown voltage substantially corresponding to the sum of the breakdown voltages of the individual devices of the composite multi-device structure.

The invention further provides for two such devices according to the teachings hereof to be electrically contacted with one another and with an electrode formed at the contact therebetween; such a combination device can be used with advantage to replace a conventional gas discharge tube surge arrester for example to protect a pair of telephone lines and their associated circuits against surges.

In order that the invention may be more fully understood embodiments thereof and their operating characteristics will now be described by way of illustrative example and by way of contrast with a prior art device, reference being had to the accompanying drawings wherein:

Figure 1 includes an enlarged sectional view of a device according to the invention;

Figure 2 is a graph of the voltage/current characteristic of the device of Fig. 1, contrasted with the characteristic of a prior art device; and

Figure 3 shows a combination device comprising two devices substantially in accordance with Fig. 1.

Referring to Fig. 1, the transient absorption semiconductor device comprises a thin planar body 1 of P type silicon of thickness of the order ot 200 μm for example doped from opposite sides to provide first and second N type regions 2, 3 of a depth of the order of 30 μm for example on either side of a P type region 4. This arrangement thus provides first and second PN junctions shown schematically at 5, 6 arranged in series and with opposite polarities. Electrode layers 7, 8 are formed on opposite sides of the body 1, and it will be appreciated that when a potential difference is applied to the electrodes one of the junctions 5, 6 will be forward biased and the other will be reverse biased.

The device is shown connected to a supply voltage source $-V$, and is arranged to protect an electric circuit 9. The circuit 9 has maximum and minimum safe rail voltages and the voltage supply $-V$ must not be allowed to vary outside of these maximum and minimum values. For the purposes of this example, it will be assumed that the maximum and minimum safe voltages are 80v and 40v. Also, it will be assumed tht the supply voltage $-V$ is from a d.c. source, although the device of the invention will work also with an a.c. source, as will become apparent hereinafter.

Now, referring to Fig. 2, a typical device according to the invention will have a V/I characteristic with the region defined by the continuous line and the hatched area on the graph. For an applied voltage $-V$ up to a given breakdown voltage V_b, the current flowing through the device is the device leakage current which is very small, for example 5 μA, as shown at 10 and this has no significant effect on the operation of the circuit 9 being protected. In this situation the PN junction 6 is forward biased, and the junction 5 is reverse biased but not such as to exceed its breakdown voltage.

When a voltage transient occurs in the supply voltage V, such as to apply to the device a voltage exceeding V_b, the reverse biased junction 5 breaks down and conducts by means of the Avalanche effect. Consequently, the device according to the invention then provides a conductive path for surge currents produced by the voltage transient, and the surge currents thus by-pass the circuit 9 to prevent it being damaged. The V/I characteristic when breakdown occurs is indicated by the hatched area 11. It will be seen that as the surge current increases, the voltage developed across the device rapidly reduces from the device breakdown voltage V_b to a predetermined non-zero value V_m and as the current increases further, the voltage remains at the value V_m at least over a considerable range of surge current. It is to be noted that on the graph, the axis representing current I has a non-linear scale. The voltage reduces to V_m when the current increases to approximately 100b mA in this example, and thereafter remains at or approximately at V_m over a large range of current values, typically up to 25 amps of peak current for the transient depending upon the physical size of the device, it being appreciated that a device configured about a relatively small silicon body will saturate sooner than the corresponding device configured about a larger silicon body.

The voltage V_m may be selected by means of control of the doping process used to make the device and principally by control of the proximity to one another of the two PN junctions by control of the dopant diffusion depths and will be selected in dependence upon the characteristics of the circuit 9 to be in excess of the minimum safe supply voltage for the circuit 9. Thus in the example given V_m may for example be selected to be 50v, i.e. 10 volts greater than the minimum safe supply voltage of 40v for the circuit 9.

The V/I characteristic of a typical conventional comparable revers biased PN junction device is shown by the broken line 12 of Fig. 2. The line 12 is illustrative of the V/I characteristic not only of a single PN junction but also of an integrated two junction device of the prior art type previously described, since in the priot art the junctions of the integrated device function independently of one another for different polarity surges. For the illustrative prior art device, the reverse biased junction breaks down at 60 volts to provide a path for the current surge, but as the surge current increases so the voltage steadily increases also. Not only is the voltage developed across the prior art device likely to increase to exceed the maximum safe level for the circuit 9, but also the heat generated in the prior device (which is a function of V × I) will be considerably greater than in the device of the invention, since the device according to the invention operates at lower voltages upon breakdown. Thus the device according to the invention not only serves the protective function more effectively but also it can be made smaller and/or with a less bulky heat dissipating encapsulation.

It is believed that the device according to the present invention exhibits the reducing voltage characteristic 11 by virtue of majority carriers from the forward biased junction 6 being swept into the junction region 5 and altering the conduction characteristics of the junction 6 after breakdown thereof. It has been found that the characteristic 11 is achieved when the PN junctions are disposed closer to one another than in a comparable integrated two junction device of the prior art, presumably allowing the majority charge carriers from the forward biased junction to migrate into the reverse biased junction and recombine therein. This theory is given by way of a suggested explanation and is not intended to limit the scope of the invention.

The values of V_b and V_m and also the shape of a particular device characteristic within the area 11 of Fig. 2 can be selected by appropriate control of doping and selection of materials and dimensions during the process of manufacture of devices according to the invention. The semiconductor body 1 conveniently comprises a (111) P-type silicon slice doped on both sides with an N-type dopant such as phosphorous, though alternative crystal orientations could be employed and the device could be constructed of N-type base material with P-type dopant. Also a different dopant than phosphorous could be used, though phosphorous is particularly convenient on account of its ease of use and the reliability and consistency of the results. The breakdown voltage of the device is largely dependant upon the bulk resistivity of the silicon body with resistivities within the range 0.95 to 1.8 Ωcm^{-3} providing V_b values of the order of 60 volts to 90 to 95 volts which are currently considered most useful in protective applications of the device. Lower resistivity material could be used to obtain lower V_b values, but there is a limit to the low end resistivities on account of the correspondingly decreased charge carrier lifetime in the material which reduces the availability of free carriers to produce the junction interaction which characterizes the present invention. Likewise, higher resistivities for example of the order of 5 or 6Ωcm^{-3} could be used to obtain devices with V_b values around 200 volts but, as previously mentioned herein and as will be further described hereinafter, for such high voltage applications it is considered preferable to series connect a number of lower voltage devices. The value of V_m is principally a function of the closeness of the two PN junctions in the device which in turn is a function of the thickness of the semiconductor body and the depth of diffusion of the junction forming regions; for example using (111) P-type silicon of thickness 220 μm (8.5 thou) and diffusing phosphorous to provide N-type regions to a depth of 30 μm (1.5 thou) and such that after doping the surface resistance of the N-type regions was around 0.7 to 0.9 Ωcm^{-2}, V_m values of the order depicted in Fig. 2 were reliably obtained.

The electrodes preferably are formed as two layer structures 7*a*, *b*, 8*a*, *b*. The layers 7*a*, 8*a* comprise plated deposited Ni, onto which is plated Au layers 7*b*, 8*b*. The resulting device can then be mounted between heat dissipating electrodes and encapsulated in a container suitable for direct mounting a printed circuit board.

It will be appreciated that the described device is symmetrical in construction so that if the supply voltage V is reversed in polarity, junction 5 becomes forward biased and junction 6 reverse biased. The device thus will operate for both polarities of applied voltage and can therefore be used in both a.c. and d.c. circuits.

Referring now to Fig. 3, there is shown therein a device which essentially comprises two of the transient absorption semiconductor devices 1 of Fig. 1 held in contact with one another by a layer of solder 10. In the embodiment of Fig. 3 an electrode 20 is further connected to the solder layer 10 for the purpose described hereinafter. The two devices in Fig. 3 are marked with the same reference numerals as are used in Fig. 1 to designate like parts with the references for the second of the devices each being marked with a prime, i.e. 1′. Each of the devices 1, 1′ operates as described above in connection with Figs. 1 and 2. The resulting three-terminal structure is particularly suited for use as a replacement component for a conventional gas discharge tube used for surge protection on telephone lines. The +V and −V electrodes are connected to positive and negative lines of a telephone cable and the centre electrode 20 is connected to earth. The three terminal device of Fig. 3 thus provides bidirectional surge protection in respect of voltage surges on either of the positive or negative lines of the telephone cable. The device can be suitably encapsulated and may typically be of a suitable size for mounting on a printed circuit board.

A device similar in construction to that of Fig. 3 but without the centre electrode would be useful in that, as aforementioned, the breakdown voltage V_b and the fold-back voltage V_m of such a two component device would equal the sum of the respective voltages of the individual devices. A composite device with a V_b of 200 volts and a V_m of 150 volts, for example, thus would comprise two individual devices coupled together with V_b for each device being 100 volts and V_m being 75 volts. A high voltage device can, by this means, be more conveniently manufactured from a number of lower voltage devices than it can be manufactured as a sole device. It is of course also to be appreciated that such a composite device could comprise three or four or even more of the individual devices of Fig. 1 series connected with one another.

CLAIMS

1. A transient absorption semiconductor device comprising a body of semiconductor material including a region of a first conductivity type disposed between regions of opposite conductivity type so as to define first and second spaced apart semiconductor rectifying junctions, first and second electrodes so arranged that when a potential difference is applied thereto one of said junctions is forward biased and the other of the junctions is reverse biased, the junctions being disposed to interact in such a manner that upon breakdown of the reverse biased junction from a relatively low conductivity state to a relatively high conductivity state and with an increase in the magnitude of the current flowing through the device, the magnitude of the potential difference developed across the electrodes decreased from that which causes said breakdown but does not decrease to a value less than a given non-zero value.

2. A transient absorption semiconductor device comprising a body of semiconductor material including a region of a first conductivity type disposed between regions of opposite conductivity type so as to define first and second spaced apart semiconductor rectifying junctions, first and second electrodes so arranged that when a potential difference is applied therebetween one of said junctions is forward biased and the other is reverse biased, the junctions being disposed closely so as to interact with the result that majority carriers from the forward biased junction are swept into the reverse biased junction in greater numbers with increasing surge current whereby upon breakdown of the reverse biased junction and with an increase in the magnitude of the current flowing through the device, the magnitude of the potential difference developed across the electrodes decreases from that which causes said breakdown but, by virtue of the modification of the characteristics of the broken down junction arising through the injection of the said majority carriers from the forward biased junction, does not decrease to a value less than a given non-zero value.

3. A transient semiconductor device as claimed in claim 1 or claim 2 wherein said body of semiconductor material comprises a thin planar body of first conductivity type having said regions of opposite conductivity type formed on opposite sides thereof.

4. A transient absorption semiconductor device as claimed in claim 3 wherein said thin planar body comprises P-type silicon and said opposite conductivity type regions comprise N-type regions doped into the P-type silicon.

5. A transient absorption semiconductor device as claimed in claim 4 wherein the N-type dopant comprises phosphorous.

6. A transient absorption semiconductor device as claimed in claim 4 or 5 wherein said thin planar body has a thickness of the order of 200 μm and said opposite conductivity type regions each extend to a depth of the order of 30 μm into the said body.

7. A transient absorption semiconductor device as claimed in any of claims 3 to 6 wherein said P-type silicon has a bulk resistivity within the range 0.95 to 1.8Ωcm^{-3} and

the surface resitivity of said N-type regions is within the range 0.7 to 0.9 Ωcm^{-2}.

8. A transient absorption semiconductor device as claimed in any of the preceding claims combined with at least one further such device connected in series with the first device.

9. A transient absorption semiconductor device as claimed in claim 8 and comprised of two such connected devices, a third electrode being formed between electrically contacting regions of said opposite conductivity type of the two devices.

10. A transient absorption semiconductor device as claimed in any of the preceding claims in combination with an electrical circuit, the said device being coupled in parallel with the said electrical circuit for protecting the said circuit from overvoltage transients.

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