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2,709,780

CONSTANT VOLTAGE SEMICONDUCTOR DEVICES

Filed Oct. 11, 1952

FIG. 1

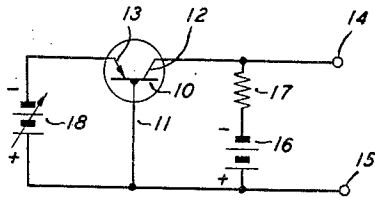


FIG. 2

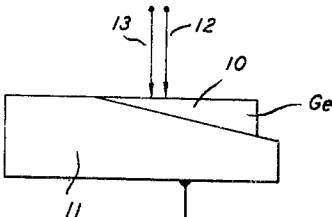


FIG. 3

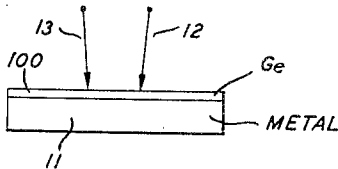


FIG. 4

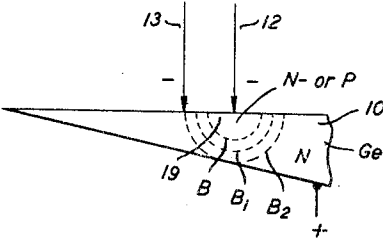


FIG. 7

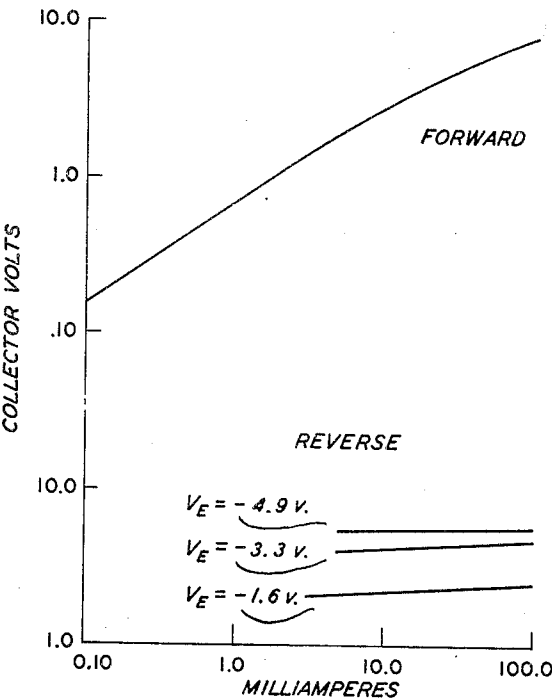


FIG. 5

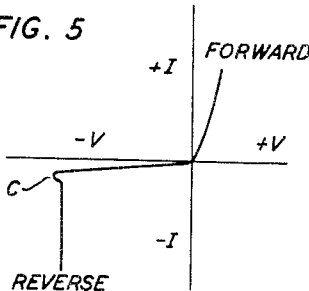
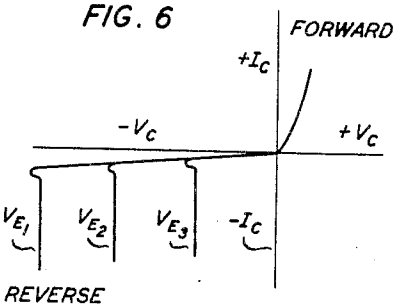


FIG. 6



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CONSTANT VOLTAGE SEMICONDUCTOR DEVICES

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6 Claims. (Cl. 323—94)

This invention relates to semiconductor devices and more particularly to such devices of the point contact type.

In a variety of electrical circuits, it is desirable and advantageous that the voltage between two points or terminals be maintained substantially constant despite substantial variations in the current between these points or terminals. Such voltage regulation has been effected heretofore in a number of different ways. However, the devices or methods known are not entirely satisfactory because of one or more factors including complexity, restrictions on the usable range of current and difficulties of fixing the voltage precisely.

One general object of this invention is to improve voltage regulating devices.

More specific objects of this invention are to simplify constant voltage devices, attain voltage regulation over a wide range of currents, and enable the ready and precise control or fixing of the constant voltage in devices of the character mentioned.

In one illustrative embodiment of this invention, a voltage regulator comprises a thin wafer or body of semiconductive material, for example germanium or silicon, a substantially ohmic connection to one major face of the body and a pair of closely adjacent rectifying or point contact connections to the opposite face of the body. Herein, for the sake of ready identification and reference, the ohmic connection will be referred to as the base and the rectifying or point contact connections as the emitter and collector.

In accordance with one feature of this invention, both the emitter and collector are biased in the reverse direction relative to the base and such that over a range of reverse collector currents the voltage between the collector and base terminals is substantially constant and of a prescribed magnitude. Particular parametral relations will be discussed in detail hereinafter. It may be noted at this point, however, that the forward collector current-voltage characteristic is substantially independent of the emitter bias. In the reverse direction, the collector current increases slowly with collector voltage up to a particular point at and beyond which the current increases abruptly but the voltage remains substantially constant. The magnitude of this voltage is a function of the reverse emitter bias, in general increasing as the reverse emitter bias increases. Thus, the constant voltage is amenable to precise and ready control or determination.

In one specific embodiment of this invention, the constant voltage device comprises a wafer of N conductivity type germanium, the wafer or a portion thereof being of the order of a few mils in thickness. A large area ohmic connection, the base, is provided to one major face of the wafer and a pair of point contacts, defining the emitter and collector, bear against the opposite face of the wafer. The collector contact is subjected to an electrical forming treatment whereby the zone of the wafer contiguous with the collector is converted toward or to P conductivity type. That is, this zone is of altered re-

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sistivity relative to the bulk of the wafer, being changed by forming to P-type, whereby a barrier is established in the bulk in proximity to the face to which the base connection obtains. The emitter makes contact with the wafer in immediate proximity to this zone. In typical devices, the bias on the emitter, negative with respect to the base, may be of the order of two to five volts whereby the constant voltage state is realized for the collector at of the order of two to six volts, also negative with respect to the base. The substantially constant voltage remains over a wide range of collector currents, say, for example, 5 to 100 milliamperes.

The invention and the above noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is a diagram representing a constant voltage device constructed in accordance with this invention;

Fig. 2 is an elevational view of a semiconductive device illustrative of one embodiment of this invention;

Fig. 3 is a view, similar to Fig. 2, of a semiconductive device illustrative of another embodiment of this invention;

Fig. 4 is a sectional view to a greatly enlarged scale of the semiconductive element in the device depicted in Fig. 2 showing particularly the zone and barrier resulting from the forming of the collector; and

Figs 5, 6 and 7 are graphs representing performance characteristics of typical semiconductor constant voltage devices constructed in accordance with this invention.

Referring now to the drawing, the device illustrated in Fig. 1 comprises a body or wafer 10 of semiconductive material, such as germanium or silicon, having a substantially ohmic base connection 11 to one face thereof and closely spaced point contacts constituting emitter and collector connections 12 and 13 to the opposite face thereof. The collector and base terminals are indicated at 14 and 15 respectively. The collector 12 is biased in the reverse direction relative to the base by a suitable source 16 in series with a resistor 17. The emitter 13 also is biased in the reverse direction by a source 18 which advantageously is variable as indicated.

When the semiconductive body or wafer 10 is of N conductivity type both the emitter and collector are biased negative with respect to the base 11. Conversely, if the body or wafer 10 is of P conductivity type the emitter and collector are biased positive with respect to the base 11.

An illustrative construction of the semiconductive element is portrayed in Fig. 2. As there shown, the body 10 is wedge-shaped in section and is affixed face-wise, as by soldering, to a metallic, for example brass, block 11 constituting the base connection. The emitter and collector 13 and 12 bear against the opposite face of the wafer 10 in the region of the thinner portion or apex of the wafer. They may be positioned as shown or equidistant from the apex of the wafer.

In a typical device the body or wafer 10 may be of N type germanium having a resistivity of the order of three to five ohm-centimeters, the wafer being approximately .10 inch square and tapered in section, and having a thickness at the region against which the emitter and collector points are placed of approximately .001 inch. In the fabrication of the device, the collector 12 is subjected to an electrical forming treatment; for example, as disclosed in the application Serial No. 67,781, filed December 29, 1948, of W. H. Brattain, now Patent 2,663,829, issued December 22, 1953, direct-current pulses may be applied between the collector and base in the reverse direction to form the collector.

In the embodiment of the invention illustrated in Fig. 3, the semiconductive wafer 100, for example of ger-

manium, is of uniform thickness throughout and is affixed to the metallic block 11 constituting the base. The collector and emitter 12 and 13 are point contacts bearing against the opposite face of the wafer. The wafer may be, for example, .10 inch square and of the order of 3 mils thick.

Advantageously, in both the embodiments above described the collector is of Phosphor bronze and the emitter 13 is of beryllium copper alloy. Also in both embodiments the collector and emitter are closely spaced, say approximately 2 or 3 mils.

The form of the collector current-collector voltage characteristic for the device of Fig. 1 is portrayed in Fig. 5. As there shown, in the forward direction the collector characteristic is essentially the same as that for a point contact semiconductor diode being substantially independent of the magnitude of the reverse emitter bias. However, in the reverse direction, the current increases slowly with increasing voltage to a point C at which the collector current increases abruptly and the voltage remains substantially constant. This phenomenon is radically distinct from the normal point contact semiconductor diode characteristic. Over a wide range of reverse collector currents, typical values for which will be given herein presently, therefore, the voltage between terminals 14 and 15 in the device of Fig. 1 will remain substantially constant.

The observed performance characteristics are explicable on a physical basis in the following manner, reference being had to Fig. 4. As a result of the electrical forming of the collector 12, there is established in the N type body 10 a zone or region 19 of altered resistivity relative to the bulk of the body and bounded by a barrier B. The zone or region 19, as indicated in Fig. 4 is altered by forming to be of P conductivity type. When the collector is biased in the reverse direction, i. e. when it is biased negative in the case of an N type body as depicted, a space charge region is established adjacent the barrier B, the thickness of the region being dependent upon both the collector current and the reverse bias potential of the adjacent emitter point.

In the vicinity of a reversely biased, i. e. negatively biased for an N type body, contact such as the emitter 13, there is a diffusion of holes or positively charged carriers away from the contact in all directions. Some of these holes will flow so as to enter the collector region, the number being dependent upon, inter alia, the magnitude of the field in the body between the emitter and collector regions. For a given negative bias upon the collector, the holes diffusing to the collector vary generally in inverse proportion to the magnitude of the emitter bias. Further, the holes which reach the vicinity of the collector will contribute to and augment the collector current and cause or result in a widening of the space charge region.

When the negative emitter bias is relatively high, the enhancement of the collector current due to the diffusing holes is small, and the barrier B has contracted so as to cause a relatively high collector resistance. However, as the emitter bias is decreased the current from the emitter to the collector increases, with consequent widening of the space charge region, reaching toward the base electrode. Viewed in another way, the space charge region of the barrier is made to approach the region of the base face of the body 10, i. e. the face in contact with the base 11. Thus, the barrier may move, in effect, to the position indicated by the dotted line B₁ in Fig. 4. If the emitter bias is decreased still further, the space charge region increases again in width so that it intersects or contacts the base 11, for example as portrayed by the dotted line B₂ in Fig. 4. When this condition is established, the collector resistance decreases abruptly and the device is transferred from a moderately high resistance-low current condition or state to a low resistance-high current state or condition.

As has been indicated hereinabove and consistent with the foregoing analysis, the point of transition to the constant voltage condition or state is dependent upon the field extant in the semiconductive body 10 between the emitter and collector. The relationship of the parameters of moment is portrayed in Fig. 6 wherein ordinates are collector current, abscissae are collector voltage and emitter bias (V_E) is the third parameter. As there shown, the negative collector voltage at which the constant reverse collector voltage condition obtains decreases as the emitter bias decreases, V_{E1} being greater than V_{E2} which in turn is greater than V_{E3} . In typical devices of the construction illustrated in Fig. 2 and described hereinabove, the collector voltage ($-V_c$) at which the device transferred to the constant voltage state was approximately -2, -4, and -6 volts respectively for emitter biases of -1.6, -3.3 and -4.9 volts, V_{E1} , V_{E2} and V_{E3} respectively. It is to be noted, however, that the forward current-voltage characteristic of the collector is essentially unaffected by changes in negative emitter bias, as illustrated in Fig. 6.

Both forward and reverse collector current-voltage characteristics for a typical device of the construction portrayed in Fig. 3 are presented in Fig. 7 for three values of negative emitter bias. For all three values, the forward characteristic is practically the same. However, the reverse characteristics are significantly different as is clear from the figure. Specifically, it will be noted that for the emitter voltages indicated the collector voltage is substantially constant at about 2.5, 4.5 and 6 volts respectively. This is true over wide ranges of current, specifically from about 5 to about 100 milliamperes.

What is claimed is:

1. A constant voltage device comprising a body of semiconductive material having a pair of opposed faces, said body having therein and extending from one of said faces into proximity to the other of said faces, a zone of different conductivity than the bulk of said body, a substantially ohmic base connection to said other face, a collector connection to said zone, an emitter connection to said body in proximity to said zone but outside thereof, means biasing said collector connection in the reverse direction relative to said base connection, and means for maintaining the collector to base voltage substantially constant at a prescribed value comprising means biasing said emitter connection in the reverse direction relative to said base connection.

2. A constant voltage device in accordance with claim 1, wherein said body is of germanium.

3. A constant voltage device in accordance with claim 1, wherein the thickness of said body at the region of said collector connection is of the order of a few mils.

4. A constant voltage device comprising a pair of terminals, a wafer of semiconductive material having a pair of opposed face portions spaced of the order of a few mils, said wafer having therein and extending from one face portion into proximity to the other of said face portions, a zone of different conductivity than the bulk of said wafer, a base connection to one of said portions, a pair of closely adjacent point contacts bearing against the other of said portions, said base connection and one of said point contacts being connected to a respective one of said terminals, means biasing said one point contact in the reverse direction relative to said base connection, and means for biasing the other of said point contacts in the reverse direction relative to said base connection and at a potential to maintain the voltage between said terminals substantially constant.

5. A constant voltage device in accordance with claim 4 wherein said wafer is wedge shaped and said point contacts bear against said wafer in proximity to the apex thereof.

6. A signal translating device comprising a body of N type germanium having a portion of the order of a few mils in thickness, a substantially ohmic base connection

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to one face of said portion, said body having therein at
said portion and extending inwardly from the opposite
face a zone of lower conductivity than the bulk of said
portion, a point collector connection to said zone, means
biasing said collector connection negative with respect 5
to said base connection, a pair of terminals one connected
to each of said collector and base connections respec-
tively, and means for maintaining the voltage between
said terminals substantially constant at a preassigned
value comprising a point emitter bearing against said 10

opposite face in proximity to said zone and means bias-
ing said emitter negative with respect to said base con-
nection.

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