

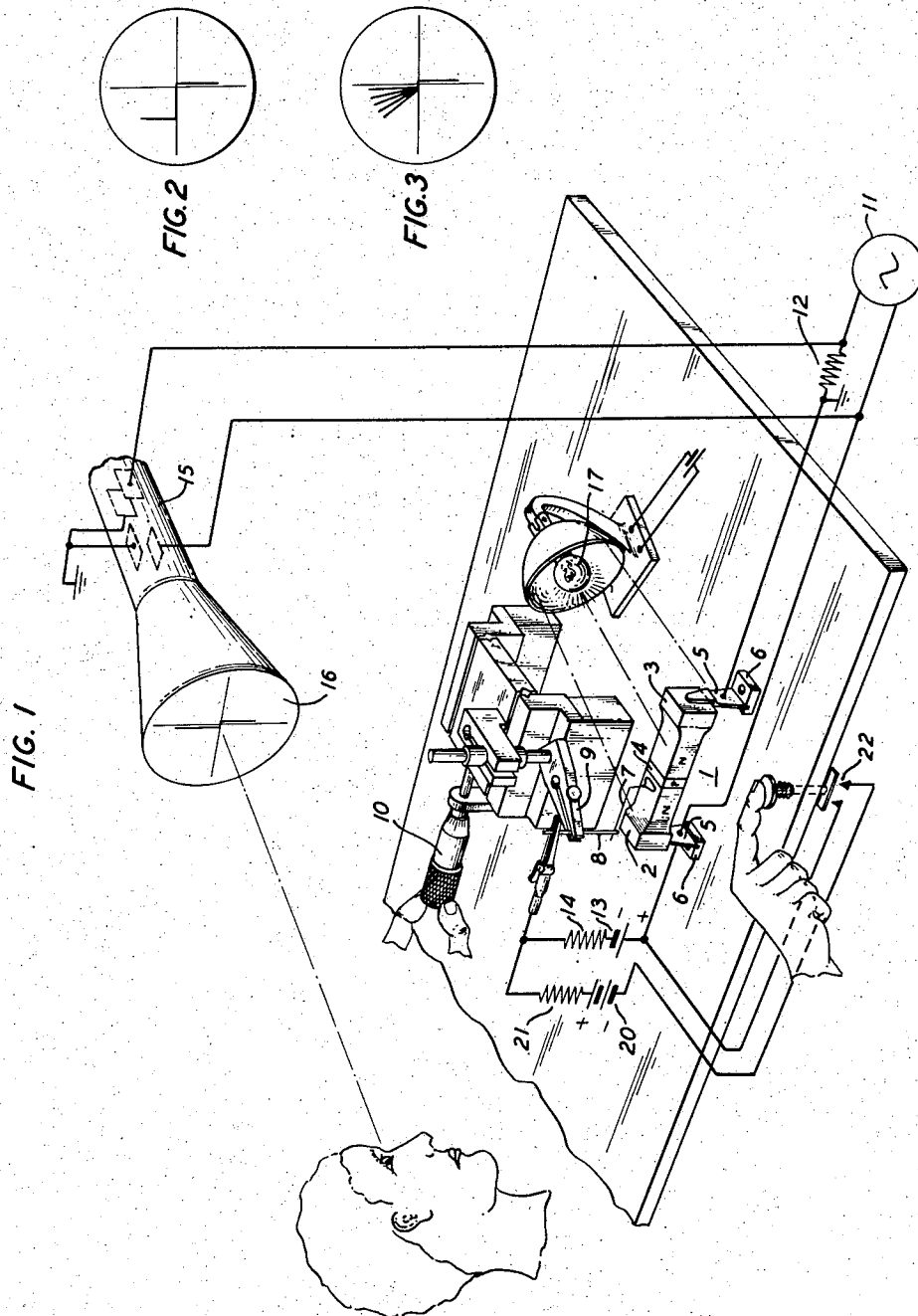
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FABRICATION OF JUNCTION TRANSISTORS

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FABRICATION OF JUNCTION TRANSISTORS

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This invention relates to the fabrication of minute circuit components and in particular to the fabrication of double junction transistors, especially for high frequency use.

Such a junction transistor comprises a bar of a semiconductor material such as germanium of which the two end portions are of one conductivity type, for example N-type, while an intermediate zone, usually in the form of a thin layer extending transversely of the longest dimension of the bar, is of opposite conductivity type, e. g., P-type.

By the very nature of the conduction which takes place within a transistor in the course of its operation, its high frequency cutoff depends on its size, and the higher the frequency at which it is to be employed, the more minute it must be. To reduce transit time effects, and so increase the high frequency cutoff, the width of the intermediate zone should be very small indeed. Furthermore, the cross section of the semiconductor bar itself at the intermediate zone should also be very small, although not as small as the width of the zone. For a bar of given dimensions it is explained in Wallace Patent 2,695,930 that improvement in high frequency operation can be achieved by effectively constricting the area of the intermediate zone still further, e. g., by the application of an electrical bias extending from side to side of the intermediate zone between electrodes bonded thereto. By employment of all of these techniques together it has been possible to achieve satisfactory operation of a junction transistor at frequencies of the order of 700 megacycles per second and higher. This, however, requires a semiconductor bar having in the approximate center thereof an intermediate zone whose thickness is of the order of 0.2 mil and whose cross section is of the order of 8 mils square. (Here and elsewhere in the present specification, the term "mil" designates $\frac{1}{1000}$ inch.) The determination of the location of this minute layer on the bar and the bonding of the base electrodes to opposite sides of it presents a problem to an operator which taxes his ability to the utmost, even though he be provided with a microscope and a micromanipulator.

Accordingly, the principal object of the invention is to determine the exact location, on a minute bar of semiconductor material which is principally of one conductivity type, of a still more minute intermediate zone of opposite conductivity type, thereupon to bond one or more electrodes to this intermediate zone, and to perform these operations with rapidity, certainty and reliability.

The searching operation is advantageously carried out through the agency of a minute probe to which a reverse base bias is applied, while working current flows from end to end of the bar. With this arrangement, when the probe engages the intermediate layer the bar operates in accordance with transistor principles and the probe, now playing the part of the base electrode of a transistor and being reversely biased, acts to hold the

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transistor in its cutoff state. When, however, the probe engages the material of either end of the bar, no transistor action takes place, and the collector current is unchanged. Thus monitoring the collector current, as by observation of the current-voltage characteristics of the bar as represented on the screen of an oscilloscope during the probing process, enables the operator to determine whether the probe is engaged with the P-type layer or not.

In order to accentuate the difference in behavior which takes place when the probe engages the P-type layer, it has been found advantageous to flood the bar with light during the probing process. This takes advantage of the photodiode characteristics of the bar which differ as between the emitter junction and collector junction.

In the course of carrying out this process it has been found, when the probe is in the neighborhood of either of the junctions, that the indication furnished by the measuring apparatus, e. g., the pattern on the oscilloscope screen, is frequently indefinite, erratic and fluctuating, as though electrical contact made by the probe with the bar were intermittent or in a state of rapid oscillation from side to side of the junction. Such an indication naturally presents the operator with uncertainty as to the exact location of his probe. Accordingly a specific object of the present invention is to remove such uncertainty. This object is accomplished, in accordance with the present invention, by momentarily applying a brief current pulse to the probe, immediately prior to the monitoring of the characteristic of the bar. This pulse should be of sign opposite to the probe bias, and may advantageously be of greater magnitude.

It has been found that, after such a momentary opposite-sign pulse, a measurement made when the reverse bias is again restored provides a clear and unambiguous indication of the location of the probe with respect to the junction, and that the latter may thus be located with a precision which can be confidently relied on to at least $\frac{1}{20,000}$ inch.

The invention will be fully apprehended from the following detailed description of an illustrative embodiment thereof taken in connection with the appended drawings in which:

Fig. 1 is a perspective drawing showing a semiconductor bar which an operator is probing to locate an intermediate layer of opposite conductivity type from the body of the bar, while carrying out the method of the invention;

Figs. 2 and 3 are diagrams illustrating the current-voltage characteristics of such a bar as they appear on the screen of an oscilloscope under various conditions of probe location and of pulsing.

Referring now to the drawings, Fig. 1 shows a semiconductor bar 1, e. g., a bar of germanium of which the end portions 2, 3 are of N-type conductivity while a minute layer 4 extending transversely from side to side of the bar and at some unknown location intermediate its ends, is of P-type conductivity. The left-hand end portion of the bar is separated from the intermediate layer by an emitter junction and the right-hand end portion is separated from the intermediate layer by a collector junction. Such a bar may be cut from a much larger single crystal of germanium which has been fabricated by the so-called "rate drawing" process of an application of E. Buehler and G. K. Teal, Serial No. 234,408, filed June 29, 1951. The bar may be supported between spring terminals 5 fixed to insulating supports 6.

The probe 7 with which the bar is to be searched is preferably a fine wire 7 of a tough, ductile conductive metal. An alloy of gold containing about 2 per cent of gallium has been found to serve well. This wire, whose diameter is of the order of 1.6 mils, is supported, as by

welding to a much thicker metal rod, for example a nickel wire 8 of about 10 mils diameter. The unsupported end of the wire is bent through a right angle for a length of about 15 mils and the tip of the bent portion is reduced to a thickness substantially less than 1.6 mils. While this reduction may be secured by shearing the wire at an angle to provide a chisel edge, it may instead with advantage be formed into the shape of a paddle as by squeezing it in a vise. The squeezing operation and the mounting of the wire are such that the long dimension of the paddle tip extends transversely of the long dimension of the germanium bar 1 and hence parallel with the long dimension of the (as yet unlocated) P-type layer 4.

The nickel wire 8 to which the gold probe 7 is welded is supported in a clamp 9 which is mounted for precise controlled movement parallel with the axis of the bar 1 as by a conventional micromanipulator. This movement may be actuated by a micrometer screw 10 bearing a calibrated sleeve.

While the electrical measurement which is relied on to furnish an indication of the location of the probe on the bar may be of any desired sort, a simple and convenient one, which takes full advantage of the properties of the transistor, is to apply an alternating voltage, e. g., of 60 cycles per second, across the two end terminals of the bar, and a steady bias of appropriate polarity to the probe. To this end an alternating-current source 11 is connected through a load resistor 12 to the two ends of the bar 1 while a current source, i. e., a battery 13 in series with a high resistor 14, is connected to the probe-supporting clamp 9, poled to supply negative voltage to the clamp. The voltage which appears across the load resistor 12 may be applied to the horizontal deflection plates of a cathode ray oscilloscope 15 so that the horizontal coordinate of the resulting pattern as it appears on the oscilloscope screen is proportional to the current flowing through the collector electrode 3 of the bar 1. At the same time the voltage which appears across the bar 1 may be applied to the vertical deflecting plates of the oscilloscope 15. With this arrangement the pattern displayed on the oscilloscope screen 16 represents the current-voltage characteristic of the bar 1.

In operation, the probe 7 is advanced by minute steps while the pattern on the oscilloscope screen 16 is examined. While the probe is still in engagement with the emitter end portion 2 of the bar 1 the pattern on the screen is merely that which results from the flow of current through the emitter junction and the collector junction in series. Inasmuch as each of these junctions exhibits a rectifier characteristic, and for each polarity of the actuating voltage one of them is biased in the forward direction and the other in the reverse direction, the resulting pattern on the oscilloscope screen 16 is the well-known current-voltage characteristic of two opposed rectifiers as illustrated in Fig. 2. Illumination of the bar, as by a lamp 17, takes advantage of the photodiode characteristics of the two junctions and so accentuates the break near the center of this pattern, and engagement of the negatively biased probe 7 with the emitter end 2 of the bar is of substantially no effect.

Once the probe 7 has been advanced past the emitter junction and makes firm electrical contact with the P-type layer 4, it can serve as the base electrode of a transistor. Its negative bias acts to hold the transistor in its cutoff state, and so greatly reduces the collector current. This effect is accentuated by illumination of the bar, and it is represented on the oscilloscope screen by a pattern having the configuration shown on the screen 16 of Fig. 1.

However, especially under strong illumination, when the probe has been advanced to or beyond the emitter junction, the pattern sometimes continues without alteration, frequently breaks up in a random fashion, and sometimes dances. A representative appearance of such a pat-

tern is shown in Fig. 3. This effect normally continues until the probe has been advanced well past the emitter junction and, indeed, to the vicinity of the collector junction. Thus, the indication of the locations of the two junctions, and hence of the location of the P-type layer between them, becomes indefinite and uncertain.

But merely by the application of a momentary pulse of current to the probe, of the opposite sign to that which flows under the influence of the steady bias source, any one of these irregular or dancing patterns is immediately converted into a positive pattern, either of the character shown in Fig. 2 indicating that the probe has not yet reached the P-type layer, or has passed it, or of the character shown in Fig. 1 which indicates with equal certainty that the probe is engaged with the P-type layer. Furthermore a steady pattern of the Fig. 2 variety is often converted by the momentary current pulse into a pattern of the Fig. 1 variety. Just as the indefinite, erratic and dancing patterns appear to indicate indeterminate or oscillating contact of the probe with the bar, so the positive patterns which result from the current pulse appear to indicate firm, stationary and conductive contact of the probe with the bar. As a result of the application of the current pulse it has become possible to increase the fineness of determination of the locations of the two junctions and of the P-type layer between them by a factor ten or more.

The current pulse which has this advantageous effect is conveniently secured by connection of an auxiliary battery 20, in series with a resistor 21 and a manually controlled switch 22, to the probe-supporting clamp 9 as shown in the figure. The polarity of the battery 20 is opposite to that of the steady probe bias battery 13. Thus, with a bar of N-type material having an intermediate layer of P-type material the steady bias of the probe is negative with respect to the emitter end 2 of the bar while the pulse bias is positive with respect to the emitter end of the bar. Of course, if the conductivity types of the several portions of the bar were interchanged the polarities of both batteries should be interchanged accordingly.

Preferably, though not necessarily, the magnitude of the pulse bias battery is at least twice that of the steady bias battery. With approximately equal magnitudes for the series resistors 14 and 21, e. g., $\frac{1}{2}$ megohm, closure of the switch momentarily applies a positive electrical pulse to the bar. Specifically, the battery 13 may be of 3 to 6 volts and the battery 20 of 10 to 20 volts.

Without necessary subscription to any particular theory as to the mechanism by which application of the momentary current pulse to the probe provides these considerable advantages, the following conjecture may be advanced. It is known that the exterior surface of the P-type layer, when in contact with the probe, bears a microscopic film, due to the presence of moisture, chemical action or merely due to surface charge considerations as discussed, for example by J. Joffe in *Electrical Communication* for 1945, volume 22, page 217, and that the electrical characteristics of this film are N-type rather than P-type. Hence, a microscopic rectifier barrier may exist between the body of the P-type material and the metal of the probe, which presents a very high impedance to the voltage of the steady bias source. With contacts as fine as those here under consideration the normal vibration of a laboratory building, otherwise completely unnoticeable, may well cause the minute shifts in the point of contact, and so an unstable pattern on the screen. It is consistent with these considerations and with the experimentally verified action of the current pulse that the latter should cause a minute, perhaps even a monomolecular, bond extending from the metal of the probe to the P-type semiconductor material below it, thus establishing a solid ohmic connection between the probe and the P-type material. The bond, if it exists, is of such fineness as to be mechanically unnoticeable inasmuch as

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an advance of the probe, even by a small fraction of a mil, breaks the bond and brings the probe into a position in which a new current pulse can establish a new ohmic connection to an adjacent portion of the P-type layer.

What is claimed is:

1. The method of determining the exact location, on a semiconductor body of which the end portions are of one conductivity type, of an intermediate zone of opposite conductivity type, which comprises applying a voltage from end to end of said body, engaging a probe with said body, biasing said probe in the reverse polarity with respect to the material of said intermediate zone, advancing said probe in steps over the surface of said body, causing a momentary current pulse to flow through said probe to said body after each step, thereby to establish ohmic contact between said probe and said body, measuring the current flowing through said body, and noting the location of said probe on said body at which the current flowing through said body is significantly modified by the joint influence of the bias on said probe and of said current pulse.

2. The method of determining the exact location, on a semiconductor body of which at least one portion is of one conductivity type and a contiguous portion is of opposite conductivity type, of a junction separating said portions, which comprises applying a voltage from end to end of said body, engaging a probe with said body, biasing said probe in a preassigned polarity with respect to said body, advancing said probe over the surface of said body, causing a succession of momentary current pulses to flow through said probe to successively different parts of said body, thereby to establish ohmic contact between said probe and said body, measuring the current flowing through said body, and noting the location of said probe on said body at which the current flowing through said body is significantly modified by the joint influence of the bias on said probe and of said current pulse.

3. The method of determining the exact location, on a semiconductor body of which the end portions are of one conductivity type, of an intermediate zone of opposite conductivity type which comprises applying a voltage from end to end of said body, engaging a probe with said body, biasing said probe in a preassigned polarity with respect to said body, advancing said probe over the surface of said

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body, causing a succession of momentary current pulses to flow through said probe to successively different parts of said body, thereby to establish ohmic contact between said probe and said body at each of said parts, measuring the current flowing through said body after each of said pulses, and noting the location of said probe on said body at which the current flowing through said body is significantly modified by the joint influence of the bias on said probe and of said current pulse.

4. The method of determining the exact location, on a semiconductor body of which an emitter end portion and a collector end portion are of one conductivity type, of an intermediate zone of opposite conductivity type, said end portions being equipped with an emitter terminal and a collector terminal respectively, which comprises engaging a probe with said body, said probe constituting a third terminal, applying a voltage between said collector terminal and one of said two other terminals, advancing said probe over the surface of said body, causing a succession of brief current pulses to flow through said probe to successively different parts of said body, thereby to establish ohmic contact between said probe and said body at each of said parts, measuring the current flowing through said collector terminal after each of said pulses, and noting the location of said probe on said body at which said collector current is significantly modified by said probe.

5. The method of determining the exact location, on a semiconductor body of which at least one portion is of one conductivity type and a contiguous portion is of opposite conductivity type, of a junction separating said portions, said one portion being equipped with a terminal, which comprises, engaging a probe with said body, said probe constituting another terminal, applying a voltage between said terminals, advancing said probe over the surface of said body, causing a succession of brief current pulses to flow through said probe to successively different parts of said body, thereby to establish ohmic contact between said probe and said body at each of said parts, measuring the current flowing through said terminals after each of said pulses, and noting the location of said probe on said body at which said current is significantly modified by said probe.

No references cited.