

PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Method of Manufacturing Electrical Semiconductor Devices

WE, TEXAS INSTRUMENTS INCORPORATED, of 6000 Lemmon Avenue, Dallas, Texas, United States of America, a corporation organized and existing under the laws of the State of Delaware, 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 method of manufacturing electrical semiconductor devices, and more particularly to a method of mass-producing silicon diodes or the like. One of the known methods of producing electrical semiconductor diodes starts with a very small piece of silicon of n-type conductivity. To one face of this piece of silicon an electrical connection is made in such a way as to form a rectifying junction, and to another face of this piece of silicon an electrical connection is made in such a way as to form an ohmic, or non-rectifying connection. This can be done, for example, by pressing the end of an aluminium wire against one face of the silicon and heating the point of contact until the aluminium and the silicon alloy sufficiently to make a connection and to convert the adjacent silicon into a p-type conductivity material. The result is a rectifying junction. A similar connection may be made to another surface of the silicon, using a gold wire having a very small percentage of antimony in it, and this connection will be an ohmic, or non-rectifying, connection, since the gold-antimony alloy does not convert the adjacent silicon into p-type conductivity material.

For most purposes, the diodes so formed may be minute in size and, of course, it is cheaper and more efficient to make the devices quite small. The usual diode of this type consists of a silicon wafer that is only a few thousandths of an inch in thickness and of the order of one- or two-tenths of

an inch square. The wires that connect to it are generally only one- or two-thousandths of an inch in diameter. As a result, the cutting of the silicon into such small pieces, the handling of those pieces, and the positioning and attaching of the wires becomes an intricate, delicate job, most of which must be accomplished under a watch-maker's glass and by the use of delicate, expensive tools. It is this tedious, expensive assembly operation that the present invention proposes to avoid.

Briefly, the method of the present invention comprises the formation of a sheet, or plate, or strip of semiconductor material of predetermined electrical conductivity characteristics such as a sheet of silicon of n-type conductivity, as distinguished from a great multiplicity of tiny bits of silicon. To this sheet of material a whole series of electrical junctions are then made at predetermined spaced intervals. In the preferred embodiment junctions are made on each side of the sheet, and in corresponding relationship. One set of these junctions are rectifying junctions, and the other set, positioned opposite to it, are non-rectifying junctions. The resultant silicon plate, with its set of rectifying junctions on one side and its corresponding set of non-rectifying junctions on the other side, is thereafter cut up into a large number of individual diodes by the use of an apparatus known under the Registered Trade-Mark "Cavitron" or some other device which will cut the silicon sheet between the sets of junctions.

It will at once be apparent that semiconductor diodes may be made in this same general manner from either n-type or p-type conductivity silicon, from either n-type or p-type conductivity germanium, or from any other similarly acting semiconductor material. It will also be apparent that the rectifying junction may be made not only by a combination of an aluminium wire

[Price 3/6]

Price 4s 6d

and silicon of n-type conductivity, but also by alloying with either n-type or p-type conductivity semiconductor material any one of many other types of metal or alloy, if the metal or alloy to be alloyed with the semiconductor is selected so that the result of the alloying together will convert a part of the semiconductor material to a conductivity type different from the rest of the semiconductor material, and thus form a rectifying junction. In a similar way, the ohmic connection may be made between a gold-antimony alloy wire and an n-type silicon wafer, or it may be made by alloying together any other semiconductor material and a wire selected from materials that will form an ohmic connection, and not a rectifying connection, with that semiconductor material when so alloyed. The principles governing this are too well known to need further elucidation.

Further details and advantages of this invention will become apparent from a consideration of the accompanying drawings which illustrate the preferred embodiment of this invention, together with the following detailed description of the practice of this invention in accordance with that embodiment. In the drawings:

Figure 1 is a perspective view of a grown silicon crystal from which a silicon wafer for the purpose of this invention is to be taken;

Figure 2 is a perspective view of a wafer or disk of silicon cut from the crystal of Figure 1;

Figure 3 is a plan view of a jig or fixture for the purpose of holding wires in the proper position for attachment to the disk of Figure 2, in accordance with the principles of this invention;

Figure 4 is a cross-section of the jig of Figure 3, taken on lines 4-4 of Figure 3;

Figure 5 is a fragment of the device as shown in Figure 4, on an enlarged scale, and showing certain wires in place, ready for the formation of junctions with the silicon plate, which is also shown in place in the jig;

Figure 6 is a view partly in section of a part of a disk such as is shown in Figure 2, with a series of wires attached to it, forming junctions with it;

Figure 7 is a view similar to Figure 5, but showing the jig inverted, and with a second series of wires in position to form junctions opposite to the first set of junctions that have already been formed as illustrated in Figures 5 and 6;

Figure 8 is a view similar to Figure 6, but showing the second set of junctions attached to the plate;

Figure 9 is a plan view of a plate such as is shown in Figure 2, with a series of wires attached to it to form junctions with

it, as illustrated in Figures 5, 6, 7 and 8. This figure also shows the lines along which the plate is to be cut into individual diodes.

Figure 10 is an elevational view of an individual diode as formed by cutting the plate shown in Figure 9.

In describing the embodiment of the invention illustrated in the drawings, reference will be made to specific materials, which, while preferred, can be changed, as has been indicated above. Thus, it is preferred to practice the invention by starting with a grown silicon crystal 20, as shown in Figure 1. Such crystals are customarily grown from a molten mass of silicon in what is known as a crystal-pulling machine, which starts with a seed of silicon of a desired type, brings that seed of silicon into contact with the surface of a molten bath of silicon and then proceeds to rotate the seed crystal and pull it from the bath, pulling a large crystal upon it. The crystal, when it leaves the bath, has somewhat the appearance shown in Figure 1, and usually weighs around 50 grams. A crystal such as that shown in Figure 1 may consist entirely of silicon of one conductivity type, or it may be made to change at some point in its growth from one type conductivity to another or to contain a thin, transversely extending layer of silicon of the opposite type of conductivity from that of the remainder of the crystal. This latter is commonly the case where the crystal is to be used to form grown junction transistors rather than diodes.

As illustrated in Figure 2, a section 21 has been cut transversely from the crystal 20, as indicated by the dotted lines in Figure 1. According to the preferred form of this invention, the wafer 21 is of n-type conductivity, although it may be of p-type conductivity, or it may contain a transverse layer of a conductivity type different from the remainder of the wafer. This transverse layer can either lie between two layers of a different conductivity type or may lie along one surface of the wafer 21. Such variations in the nature of the layer 21 will produce differences in the final product and its electrical characteristics, dependent upon what these variations are. It will at once be apparent, however, that products resulting from such variations can also have useful electrical characteristics, and hence these variations are included within the scope of this invention.

As illustrated in Figures 3 and 4, the wafer 21 is clamped between two plates 22 and 23, which are preferably made of graphite, and which are held together and against the wafer 21 by a series of bolts 24, one positioned in each corner of the pair of plates. Plates 22 and 23 are provided with corresponding holes 25 and 26, which

serve the purpose of positioning a series of wires that are to be abutted to the plate and fastened there by alloying or fusion. The plates 22 and 23 may be made of ceramic material or other material which will stand the heat and not tend to become alloyed or attached to the wafer or the wires themselves, but graphite is preferred. After the wafer 21 has been clamped between the plates 22 and 23, a series of wires 27 are placed in the holes 25 (Figure 5) so that their ends abut a surface of the wafer 21, and the whole assembly is heated so that the ends of the wires become alloyed with the wafer (Figure 6). In the preferred embodiment, the set of wires 27 is made of gold with approximately one percent of antimony added. Heating to a temperature of about 1000°C. for a period of approximately one-half minute will affix these wires satisfactorily to form ohmic junctions with the wafer 21.

The jig shown in Figure 5, with the wafer 21 and the wires 27 attached to it, is then inverted as shown in Figure 7 so that the wires 27 extend out the bottom holes, and a set of aluminium wires 28 is then positioned in the holes 26, which now extend upward. The assembly is again heated, this time to a temperature of around 700°C. for approximately one-half minute, and the result is an alloying of the ends of the aluminium wire to the wafer 21 and the formation of a series of rectifying junctions 30 on the upper surface of the wafer. It is preferred to fix the gold-antimony wires first as the gold wires melt at a somewhat higher temperature than the aluminium wires.

The wafer 21 then looks as shown in Figure 9, when viewed in plan, except for the lines 32, which have been drawn vertically, and the lines 33, which have been drawn horizontally to indicate the manner in which the wafer 21 is to be cut into individual diodes. The wafer is next cut as indicated by these lines, preferably by a "Cavitron" or a diamond-toothed saw, and the result is a series of diode elements 34, as illustrated in Figure 10. These may be encased and mounted in any suitable manner.

As already pointed out, there are numerous modifications that may be made in the practice of this invention, and it is intended that these shall fall within the scope of the invention and the appended claims. For example, if the wafer 21 should consist of two layers of semiconductor material extending transversely thereacross, there would be a grown junction extending transversely across the semiconductor device of Figure 10. Thus, it might not be necessary to have a rectifying junction at 30, as has been indicated, and this might be

made as an ohmic connection, and the device would still be a diode. As another variant, the wafer 21 in Figure 2 might contain a layer of p-type conductivity material sandwiched between two outer layers of n-type conductivity material by the manner in which the crystal was grown. Thus, the device shown in Figure 10 might contain a double junction extending transversely across the silicon segment. By making ohmic connections at 30 and 31, and providing a separate connection to the p-type conductivity layer extending transversely across the silicon section, a transistor would result, and this is within the scope of the present invention. In other words, the present invention is directed to a method of expediently and efficiently attaching electrical connections to small semiconductor segments and does not limit it to the exact nature or electrical characteristics of the final device.

WHAT WE CLAIM IS:—

1. A method of producing electrical semiconductor devices, which method comprises forming a sheet of semiconductor material of predetermined electrical conductivity characteristics, abutting the individual ends of a plurality of wires in spaced relationship against one surface of said sheet, heating said sheet and said wires sufficiently to cause the formation of a fused bond between each of said wire ends and said surface, and severing said sheet of semiconductor material into a plurality of individual segments provided each with one of said wires bonded thereto.

2. A method of producing electrical semiconductor devices according to Claim 1 in which said wires are of a material that will form a rectifying junction with the sheet when fused to it.

3. A method according to Claim 2 in which the semiconductor material is silicon of n-type conductivity and the wires are comprised of aluminium.

4. A method of producing electrical semiconductor devices according to Claim 1, comprising the additional steps of abutting the ends of a second series of wires in spaced relationship against the opposite surface of said sheet and heating said sheet and wires sufficiently to cause the formation of a fused bond between each of said set of wire ends and said second surface.

5. A method of producing electrical semiconductor devices according to Claim 4, in which the ends of the second series of wires on the opposite surface of said sheet are so positioned as to register with the first series of wire ends.

6. A method according to Claim 5 in which the first series of wires are of a material that will form a rectifying junction with said sheet when fused to it, and the



serve the purpose of positioning a series of wires that are to be abutted to the plate and fastened there by alloying or fusion. The plates 22 and 23 may be made of ceramic material or other material which will stand the heat and not tend to become alloyed or attached to the wafer or the wires themselves, but graphite is preferred. After the wafer 21 has been clamped between the plates 22 and 23, a series of wires 27 are placed in the holes 25 (Figure 5) so that their ends abut a surface of the wafer 21, and the whole assembly is heated so that the ends of the wires become alloyed with the wafer (Figure 6). In the preferred embodiment, the set of wires 27 is made of gold with approximately one percent of antimony added. Heating to a temperature of about 1000°C. for a period of approximately one-half minute will affix these wires satisfactorily to form ohmic junctions with the wafer 21.

The jig shown in Figure 5, with the wafer 21 and the wires 27 attached to it, is then inverted as shown in Figure 7 so that the wires 27 extend out the bottom holes, and a set of aluminium wires 28 is then positioned in the holes 26, which now extend upward. The assembly is again heated, this time to a temperature of around 700°C. for approximately one-half minute, and the result is an alloying of the ends of the aluminium wire to the wafer 21 and the formation of a series of rectifying junctions on the upper surface of the wafer. It is preferred to fix the gold-antimony wires first as the gold wires melt at a somewhat higher temperature than the aluminium wires.

The wafer 21 then looks as shown in Figure 9, when viewed in plan, except for the lines 32, which have been drawn vertically, and the lines 33, which have been drawn horizontally to indicate the manner in which the wafer 21 is to be cut into individual diodes. The wafer is next cut as indicated by these lines, preferably by a "Cavitron" or a diamond-toothed saw, and the result is a series of diode elements 34, as illustrated in Figure 10. These may be encased and mounted in any suitable manner.

As already pointed out, there are numerous modifications that may be made in the practice of this invention, and it is intended that these shall fall within the scope of the invention and the appended claims. For example, if the wafer 21 should consist of two layers of semiconductor material extending transversely thereacross, there would be a grown junction extending transversely across the semiconductor device of Figure 10. Thus, it might not be necessary to have a rectifying junction at 30, as has been indicated, and this might be

made as an ohmic connection, and the device would still be a diode. As another variant, the wafer 21 in Figure 2 might contain a layer of p-type conductivity material sandwiched between two outer layers of n-type conductivity material by the manner in which the crystal was grown. Thus, the device shown in Figure 10 might contain a double junction extending transversely across the silicon segment. By making ohmic connections at 30 and 31, and providing a separate connection to the p-type conductivity layer extending transversely across the silicon section, a transistor would result, and this is within the scope of the present invention. In other words, the present invention is directed to a method of expediently and efficiently attaching electrical connections to small semiconductor segments and does not limit it to the exact nature or electrical characteristics of the final device.

WHAT WE CLAIM IS:—

1. A method of producing electrical semiconductor devices, which method comprises forming a sheet of semiconductor material of predetermined electrical conductivity characteristics, abutting the individual ends of a plurality of wires in spaced relationship against one surface of said sheet, heating said sheet and said wires sufficiently to cause the formation of a fused bond between each of said wire ends and said surface, and severing said sheet of semiconductor material into a plurality of individual segments provided each with one of said wires bonded thereto.

2. A method of producing electrical semiconductor devices according to Claim 1 in which said wires are of a material that will form a rectifying junction with the sheet when fused to it.

3. A method according to Claim 2 in which the semiconductor material is silicon of n-type conductivity and the wires are comprised of aluminium.

4. A method of producing electrical semiconductor devices according to Claim 1, comprising the additional steps of abutting the ends of a second series of wires in spaced relationship against the opposite surface of said sheet and heating said sheet and wires sufficiently to cause the formation of a fused bond between each of said set of wire ends and said second surface.

5. A method of producing electrical semiconductor devices according to Claim 4, in which the ends of the second series of wires on the opposite surface of said sheet are so positioned as to register with the first series of wire ends.

6. A method according to Claim 5 in which the first series of wires are of a material that will form a rectifying junction with said sheet when fused to it, and the

second series of wires are of a material that will form a non-rectifying junction with said sheet.

7. A method according to any one of
5 Claims 4 to 6 in which the first series of wires are aluminium, the sheet is silicon of n-type conductivity and the second series of wires is of gold containing a small amount of antimony.

10 8. A method of producing electrical semiconductor devices substantially as

described with reference to the accompanying drawings.

9. Electrical semiconductor devices when produced by the method according to any 15 one of the preceding claims.

For the Applicants,
F. J. CLEVELAND & CO.,
Chartered Patent Agents,
29 Southampton Buildings,
Chancery Lane,
London, W.C.2.

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