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PATENT SPECIFICATION

Inventors: MORTON EDWARD JONES and WILLIS ALFRED ADCOCK

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COMPLETE SPECIFICATION

Grown Junction Type Transistors and method of making same

We, TEXAS INSTRUMENTS INCORPORATED, of 6000, Lemon Avenue, Dallas, Texas, United States of America, a corporation organised 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 grown junction type silicon transistors and to a method for their manufacture. In particular this application relates to a method for growing silicon crystals suitable for use in the manufacture of junction type transistors of the *n-p-n* type and to a method of making electrical connections to segments taken from such crystals.

Silicon, like germanium, exhibits semiconductor characteristics and it has been discovered that silicon crystals can be grown in such a manner as to produce an *n* type section suitable for use as the collector section of a transistor, a very thin *p* type section, and a second *n* type section suitable for use as an emitter and separated from the first *n* type section by the *p* type section. It has also been discovered that satisfactory electrical connections can be made to each of these three sections in a simple and efficient enough fashion to avoid the production of a large percentage of rejects.

Briefly, according to this invention, the junction containing crystal may be formed in a crystal pulling device which rotates and draws the crystal upon a seed crystal from a bath of molten silicon, in an atmosphere of helium. A small quantity of an element from Group 5 of the Periodic system such as antimony is added as an impurity at the beginning of the operation and about half of the crystal then drawn as *n* type crystal suitable for use as the collector portion of the final transistor. A quantity of an element from Group 3 of the Periodic system such as aluminum is then added to the molten silicon and a thin layer of crystal drawn onto the collector portion. This thin layer is *p* type crystal and is usually from 0.1 to 2 mils (0.0001 to 0.002 inches) in thickness. A fairly large quantity of an element from Group 5 of the Periodic system such as arsenic is next added to the melt and the remainder of the crystal drawn, and this part of the crystal will be *n* type crystal suitable for use as the emitter portion of the eventual transistor.

The crystal so formed may next be cut into segments each about 0.200 inches in length and about 0.040 inches square. Each crystal section is so cut that the ends are of *n* type crystal and these ends are separated by a thin layer of *p* type crystal. The crystal segments may then be etched to reveal the position of the *p* type layer, the ends sandblasted and nickel plated so that supporting connections can be soldered thereto, and one or more connections made to the *p* type layer by pressing the end of an aluminum wire against the crystal in the plane of the *p* type layer and heating the crystal and aluminum wire sufficiently so that the end of the aluminum wire will alloy with and attach itself to the crystal at that point. The junction of the aluminum wire and the crystal may then be etched to remove any direct connection between the aluminum wire and the *n* type end portions of the crystal section.

The invention will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1a is a perspective view of a crystal segment grown and cut in acordance with the preferred practice of this invention. Figure 1b is a perspective view of the same crystal segment as it appears after being etched.

Figure 2 is a sectional view of the same crystal segment with an aluminum wire attached, in accordance with the principles of this invention, to the *p* layer of the crystal.

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Figure 3 is a perspective view of the same crystal with headers or supporting wires attached to the opposite ends thereof and a single aluminum wire attached to the *p* layer.

Figure 4 is a perspective view of a similar attached to the opposite ends thereof and a single aluminum wire attached to the *p* layer.

The usual crystal puller, not shown, will conveniently handle about 50 grams of material. It has been found desirable to grow the collector portion of the transistor crystal first and for this portion to have a resistance of about 0.5 to 2.0 ohm centimetres. It has also been found that *n* type crystal having this resistance can be produced by incorporating in this portion of the crystal about 0.5 to 2.0×10^{-7} antimony atoms per silicon atom. It is necessary to include about 1.0 to 4.0 milligrams of antimony in the 50 grams of silicon of the melt in order to obtain the proper proportion in the crystal, since the antimony does not crystallize out of the melt in the ratio in which it is present in the melt. To expedite accurate measurement of the antimony for addition to the melt it has been found desirable to prepare a silicon-antimony alloy containing about 0.3 per cent antimony, and to add a more easily measurable quantity of the alloy to the melt in an amount sufficient to establish the required percentage of antimony therein.

After about half of the 50 gram melt is converted into crystal, an amount of aluminum sufficient to counteract the effect of the antimony and produce a *p* type crystal with a resistivity of about 0.5 to 2.0 ohm centimeters is added to the mass. This requires an excess of about 2 to 8×10^{-7} atoms of the aluminum per atom of silicon, over that required to compensate for the antimony present, or a total of about 2.5 to 10×10^{-7} atoms of aluminum per atom of silicon. This amounts to about .0015 to .006 milligrams of aluminum for the remaining 25 grams of melt, but since the distribution factor for aluminum is low and only a very small part of the aluminum passes from the melt into the crystal, it requires about 0.75 to 3 milligrams of aluminum in the 25 grams of melt remaining in order to get the required amount of aluminum into the *p* layer. The *p* layer is then drawn onto the crystal and its thickness is generally kept somewhere between 0.1 and 2 mils (0.0001—0.002 inches).

In order to prepare the mix for the drawing of the emitter portion of the crystal, it is only necessary to add a sufficient amount of arsenic to cause the formation of *n* type crystal and lower the resistivity to some very low figure, preferably something of the order of 0.01 ohms centimeters. The amount of arsenic to be added is not critical but arsenic should be present in the final crystal in the ratio of at least about 4×10^{-5} atoms of arsenic per atom of silicon. This means about 5 milligrams of arsenic in 25 grams of crystal and in order to get this much arsenic in the crystal about 50 milligrams of arsenic should be added to the melt since the arsenic is easily lost and does not all pass into the crystal.

Other elements than antimony may be added to the original mix to prepare it for the drawing of the collector portion of the crystal and those elements of Group 5 of the Periodic Table having satisfactory physical characteristics are suitable for this purpose. However, antimony is preferred since it is desired to accurately control the amount present so as to control the resistivity of the crystal, and antimony lends itself well to this control.

Similarly, other elements of Group 3 may be substituted for aluminum in the preparation of the molten mix for the drawing of the *p* layer, but aluminum is preferred because it has a low distribution factor and quite a substantial quantity must be added, and therefore the amount can be easily measured.

In the same way, other elements of Group 5 may be substituted for arsenic in making the emitter portion of the crystal but arsenic has been found to be more satisfactory.

Once the crystal has been formed it is next cut into segments of the desired size, which are usually about .040 by .040 by .200 inches with the *p* layer extending at right angles across the segment near the mid-point of its length. The segments are then etched, preferably with a mixture of hydrofluoric acid, nitric acid, acetic acid and bromine. This causes the emitter portion of the crystal to become glossy and the collector portion of the crystal to remain rough and produces a clear line of demarcation at the *p* layer. As illustrated in Figure 1a, the crystal section 10 originally has an emitter portion 11, a *p* layer 12 and a collector portion 13. They are not easily distinguishable, however, in the original crystal segment because they have generally the same appearance. However, after etching, as shown in Figure 1b, the emitter section 11 appears quite glossy or shiny, the *p* layer appears as a definite line and the collector portion 13 appears noticeably rough. This is of considerable assistance in locating the *p* layer and in determining which end of the crystal segment is which, for final assembly.

The two ends of the crystal section are next roughened, as by sandblasting, in order to help them hold a nickel plating which is then applied. Next, the crystal segment is placed in a helium atmosphere and electrically heated while the end of a 5 mil aluminum wire is pressed against the segment at the *p* layer. A microscope may be used to advantage for the purpose of observing the crystal segment and wire during this operation. This heating is continued until the contacting end of the aluminum wire softens and alloys itself with the silicon crystal section, whereupon the heating is stopped and the junction allowed to

solidify. It has been found, although the aluminum wire end extends beyond the edges of the *p* section and contacts the emitter and collector sections of the crystal segment, that during the heating and solidifying operation enough aluminum mixes with the material of the crystal adjacent portions of the section to convert the part of the crystal section immediately under the end of the wire into *p* type crystal. The connection area is again etched after it has cooled, thus removing any material that might possible connect the aluminum wire directly with either the emitter or collector sections. If a second connection to the *p* layer is desired, the crystal section may be turned over and a second aluminum wire connected in the same manner to the *p* layer on the opposite side of the crystal section. Thus two aluminum wire connections 14 and 15 may be provided if desired.

Supporting and connecting wires 17 and 18 may be soldered to the plated ends of the crystal section, as illustrated in Figures 3 and 4 and these are in turn connected to a base, not shown. The aluminum wires 14 and 15, which are quite fine, are connected to somewhat heavier wires 19 and 20 which are also mounted in the base of the unit.

The transistor, of course, may be used in the form shown but customarily it will be encased in an inert, heat conducting liquid and covered with a can or cover of some kind.

WHAT WE CLAIM IS:—

1. A method of growing a crystal for a junction transistor that comprises melting a batch of silicon containing a small proportion of an element of Group 5 of the Periodic system, drawing upon a seed crystal an *n* type crystal section, adding to the molten silicon that remains, an amount of an element of Group 3 of the Periodic system, whereby a thin layer of *p* type crystal is produced when the silicon mixture is drawn in a thin layer over the *n* type crystal already formed, adding to the melt an element of Group 5 of the Periodic System to overcome the Group 3 element in the mixture, and then drawing upon the *p* type layer a second layer of *n* type crystal.

2. A method of growing a crystal for a junction transistor as claimed in Claim 1, that comprises melting a batch of silicon containing 1.0 to 4.0 milligrams of antimony to 50 grams of silicon, drawing upon a seed crystal an *n* type crystal section, adding to the molten silicon that remains a sufficient amount of aluminum to give a concentration of 0.75 to 3 milligrams of aluminum to 25 grams of silicon, drawing a very thin layer of *p* type crystal from the melt upon the *n* type crystal already formed, adding an amount of arsenic to the melt sufficient to give an arsenic concentration in the melt of at least 50 milligrams of arsenic to 25 grams of silicon and drawing upon the already formed crystal a second layer of *n* type crystal.

3. A method of growing a crystal for a junction transistor as claimed in Claim 1 or 2, wherein an aluminum contact wire is fastened to the *p* type layer by bringing an end thereof into contact with the *p* type layer and heating the crystal segment and aluminum until the aluminum wire alloys with and fastens itself to the crystal segment.

4. A method of growing a crystal for a junction transistor as claimed in Claim 3, wherein the heating of the crystal segment and aluminum wire is carried out in an atmosphere of helium.

5. A method of growing a crystal for a junction transistor as claimed in any preceding claim, wherein the ends of the crystal are roughened, nickel-plated and thereafter connected by soldering to electrical connecting and supporting means.

6. A method of growing a crystal for a junction transistor as claimed in Claim 3 or 4, wherein an *n-p-n* silicon crystal segment has two connections to the *p* layer made by means of two aluminum wires alloyed into the surface of the crystal segment at the *p* layer.

7. A crystal junction transistor grown by the method claimed in any preceding claim and comprising an *n-p-n* silicon crystal segment, the collector section of which contains 0.5 to 2.0×10^{-7} antimony atoms per silicon atom, the base layer of which contains the same proportion of antimony atoms plus 2.5 to 10×10^{-7} atoms of aluminum per atom of silicon, and the emitter section of which contains the same proportions of antimony and aluminum plus at least 4×10^{-5} atoms of arsenic per atom of silicon.

8. A crystal junction transistor as claimed in Claim 7, in which the collector *n* section and the *p* section have a resistivity of 0.5 to 2.0 ohm centimeters, and the emitter *n* section has a resistivity no greater than 0.01 ohm centimeter.

9. The improved method of growing crystals for junction transistors substantially as described.

10. Improved junction transistor crystal grown by the method described and constructed substantially as shown in the accompanying diagrammatic drawings.

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

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solidify. It has been found, although the aluminum wire end extends beyond the edges of the *p* section and contacts the emitter and collector sections of the crystal segment, that during the heating and solidifying operation enough aluminum mixes with the material of the crystal adjacent portions of the section to convert the part of the crystal section immediately under the end of the wire into *p* type crystal. The connection area is again etched after it has cooled, thus removing any material that might possible connect the aluminum wire directly with either the emitter or collector sections. If a second connection to the *p* layer is desired, the crystal section may be turned over and a second aluminum wire connected in the same manner to the *p* layer on the opposite side of the crystal section. Thus two aluminum wire connections 14 and 15 may be provided if desired.

Supporting and connecting wires 17 and 18 may be soldered to the plated ends of the crystal section, as illustrated in Figures 3 and 4 and these are in turn connected to a base, not shown. The aluminum wires 14 and 15, which are quite fine, are connected to somewhat heavier wires 19 and 20 which are also mounted in the base of the unit.

The transistor, of course, may be used in the form shown but customarily it will be encased in an inert, heat conducting liquid and covered with a can or cover of some kind.

WHAT WE CLAIM IS:—

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2. A method of growing a crystal for a junction transistor as claimed in Claim 1, that comprises melting a batch of silicon containing 1.0 to 4.0 milligrams of antimony to 50 grams of silicon, drawing upon a seed crystal an *n* type crystal section, adding to the molten silicon that remains a sufficient amount of aluminum to give a concentration of 0.75 to 3 milligrams of aluminum to 25 grams of silicon, drawing a very thin layer of *p* type crystal from the melt upon the *n* type crystal already formed, adding an amount of arsenic to the melt sufficient to give an arsenic concentration in the melt of at least 50 milligrams of arsenic to 25 grams of silicon and drawing upon the already formed crystal a second layer of *n* type crystal.

3. A method of growing a crystal for a junction transistor as claimed in Claim 1 or 2, wherein an aluminum contact wire is fastened to the *p* type layer by bringing an end thereof into contact with the *p* type layer and heating the crystal segment and aluminum until the aluminum wire alloys with and fastens itself to the crystal segment.

4. A method of growing a crystal for a junction transistor as claimed in Claim 3, wherein the heating of the crystal segment and aluminum wire is carried out in an atmosphere of helium.

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6. A method of growing a crystal for a junction transistor as claimed in Claim 3 or 4, wherein an *n-p-n* silicon crystal segment has two connections to the *p* layer made by means of two aluminum wires alloyed into the surface of the crystal segment at the *p* layer.

7. A crystal junction transistor grown by the method claimed in any preceding claim and comprising an *n-p-n* silicon crystal segment, the collector section of which contains 0.5 to 2.0×10^{-7} antimony atoms per silicon atom, the base layer of which contains the same proportion of antimony atoms plus 2.5 to 10×10^{-7} atoms of aluminum per atom of silicon, and the emitter section of which contains the same proportions of antimony and aluminum plus at least 4×10^{-5} atoms of arsenic per atom of silicon.

8. A crystal junction transistor as claimed in Claim 7, in which the collector *n* section and the *p* section have a resistivity of 0.5 to 2.0 ohm centimeters, and the emitter *n* section has a resistivity no greater than 0.01 ohm centimeter.

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