

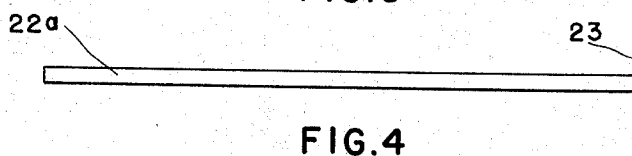
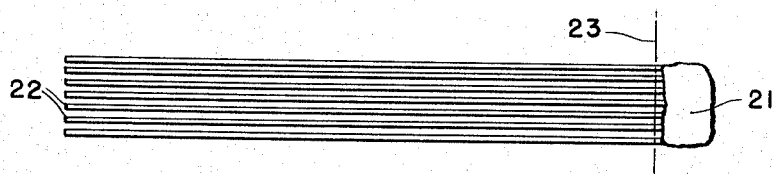
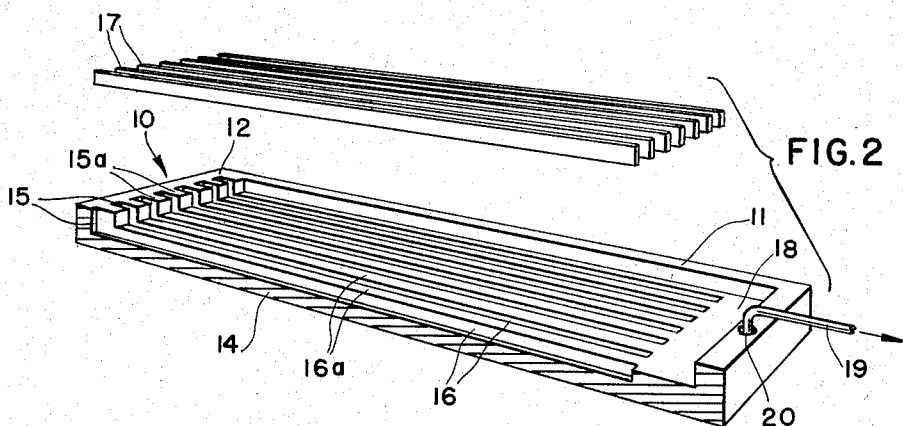
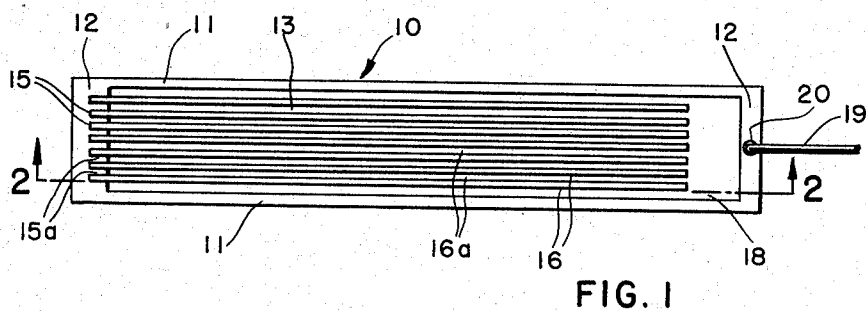
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METHOD FOR PRODUCING SINGLE-CRYSTAL SEMICONDUCTOR MATERIAL

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METHOD FOR PRODUCING SINGLE-CRYSTAL SEMICONDUCTOR MATERIAL

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This invention relates to a method and apparatus for producing single-crystal semiconductor material and more particularly, to a method and apparatus for producing thin and flat segments of n-type or p-type single-crystal semiconductor material.

One method of producing single crystals of semiconductor material now well-known in the art combines the principles of zone-leveling with the single seed crystal technique used in producing large crystals of monocrystalline structure. Zone leveling is one of the class of operations falling under the generic term of zone-melting which consists of causing a short molten zone to traverse along a charge of semiconductor material. The advantage of zone-leveling is that it gives a high degree of control over the distribution of solutes throughout a crystal and consequently, when donor or acceptor impurity material is added to a semiconductor charge, these impurities can be distributed in a highly uniform manner within the crystal. The single seed crystal technique consists essentially of bringing a seed crystal in contact with molten semiconductor material and then allowing the material to solidify whereupon the material adheres to and assumes the same crystal structure as the seed. This results in a much larger single crystal mass with a high degree of lattice perfection, uniformity of structure, and chemical purity from which can be produced a large number of semiconductor devices with identical electrical characteristics.

In this prior art method of combining zone-leveling principles with the single seed crystal technique, a charge of semiconductor material, which may be either a zone refined bar or a quantity of powdered and refined semiconductor material, is placed in a suitable high-temperature boat together with a single seed crystal. The localized source of heat required in the zone-leveling process is provided by an induction coil and a radio-frequency generator. A tube of high-temperature resistant and transparent material such as quartz contains the boat and is inserted through the open portion of the induction coil so that the energy waves radiated by the coil heat the boat and, hence, the semiconductor material. The tube serves not only to prevent the material from being contaminated by the coil but, when closed at either end except for inlet and outlet openings, provides means whereby an inert atmosphere can be maintained within the tube to prevent the material from reacting with atmospheres, such as air for example, which would otherwise be present.

To begin the process, the boat is first positioned with the junction between the single-crystal seed and the semiconductor material directly in the localized heat zone which thus reduces the material at the juncture to the molten state. Into this molten zone are added impurities of either the n-type or p-type which impurity addition may be made by melting a quantity of the semiconductor material rich in the desired type of impurity. Then, as the boat, or the tube containing the boat, is moved through the heating zone, successive portions of the semiconductor material are melted which, upon solidification, take the

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crystalline structure of the seed while the impurity material is uniformly distributed throughout the semiconductor material as the molten zone proceeds in accordance with principles of zone-leveling. By this method, a bar of single-crystal semiconductor material is produced with either n-type or p-type impurities uniformly distributed throughout the bar. This bar can then be cut up into sheets or sawed into transverse sections suitable for further dicing or sawing into the crystal segments suitable for use in fused-junction transistors and diodes.

While this method results in a single crystal of semiconductor material with very satisfactory electrical characteristics and carrier lifetime qualities, it has the disadvantage that the crystal is produced in bar form and must therefore be sawed or further sectioned in order to produce crystal segments satisfactory for use in transistors and diodes. The step of sawing or sectioning the single-crystal bar into usable segments is not only a time consuming process but requires the use of special sectioning equipment because of the hardness and brittleness of semiconductor materials. Further, the sectioning equipment is generally in the form of saws in the order of 0.01 inch to 0.02 inch in thickness and, when it is considered that the crystal segments themselves are very thin, it can be seen that the material loss due to the width of the saw cut constitutes an appreciable portion of the semiconductor material. High-frequency vibrating cutting tools are also widely used for the purpose of sectioning crystals but they too, like the saws, produce cuts comparable in thickness to the width of the saw blades.

The present invention has been conceived to overcome the disadvantages of the prior art method of producing single-crystal semiconductor bars while retaining the desirable features of producing semiconductor crystals with uniform electrical characteristics and high carrier lifetime qualities. Essentially, this method utilizes the principles of zone-leveling together with the single seed crystal technique but produces the semiconductor material in thin and flat sheets rather than in the form of a bar. These sheets of single-crystal semiconductor material, either of n-type or p-type impurity, are produced by the method and apparatus of this invention to the approximate thickness of the crystal segments used in the production of transistors and diodes so that only lapping and etching steps are required to reduce the sheets to the final desired thickness.

Accordingly, it is the principal object of this invention to disclose a method and apparatus for producing n-type or p-type single crystals of semiconductor material in the form of thin and flat segments.

It is another principal object of this invention to produce thin and flat segments of single-crystal semiconductor material with the approximate desired final thickness for use in transistors and diodes.

A further object of this invention is to produce single crystals of semiconductor material in a form which eliminates the waste of semiconductor material inherent in the prior art methods of producing crystal segments suitable for use in transistors and diodes.

A still further object of this invention is to produce crystals of semiconductor material in a form which eliminates the costly and time consuming steps of sectioning a bar of single-crystal semiconductor material into usable transistor and diode crystal segments.

The above objects will be clarified and other objects made known from the following description when taken in conjunction with the drawings in which:

Figure 1 is a plan view illustrating one form of apparatus suitable for producing single-crystal semiconductor material in the form of thin and flat sheets;

Figure 2 is a cross-sectional view in perspective taken along lines 2—2 of Figure 1;

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Figure 3 shows the manner in which the sheets of single-crystal semiconductor material are solidified onto a single seed crystal when the apparatus of Figures 1 and 2 is used; and

Figure 4 is a side-view of one of the thin and flat single-crystal semiconductor sheets separated from the single seed crystal.

Beginning now the description of this invention, a form of apparatus suitable for producing thin and flat segments of single-crystal semiconductor material is shown in Figure 1. The container 10 of Figure 1, hereinafter referred to as a boat, is constructed from graphite or any other suitable material with respect to electrical and thermal conductivity which does not contaminate the semiconductor material and which can withstand high temperatures and can be easily worked. Boat 10 is rectangular in shape, and is formed by the long sides 11, the narrow sides or ends 12, and a bottom 14. Thus formed, the long sides 11, the narrow sides or ends 12, and the bottom 14 comprise a boat which has a hollow interior portion 13.

As further illustrated in Figure 2, a series of slots 15 of any desired width are cut into one of the ends 12 of boat 10, each separated from the other by the distance designated by the numeral 15a. Likewise, a series of slots 16 are cut into the bottom 14 which slots constitute continuations of the slots 15 and are each separated from the other by the distance designated by the numeral 16a. It can thus be seen that the distances 16a between the slots 16 are equal to the distances 15a between the end slots 15 and may be, for example, 0.01 inch. A number of spacer segments 17, corresponding in height to the depth of slots 15 in end 12 and equal in length to the length of slots 16 in bottom 14, are then inserted into the slots 15 and 16 thereby providing a series of parallel partitions each separated from the other by the distance designated by the numerals 15a and 16a and maintained in position by slots 15 and 16. The spacer segments 17 are preferably but not necessarily constructed from the same type of material as boat 10. With spacer segments 17 in place in boat 10, the entire interior portion 13 of boat 10 is separated into partitions except for a space 18 adjacent the opposite end 12 of boat 10 from the slots 15. To provide for the movement of boat 10, a hole 20 is drilled in this same opposite end 12 and a long rod 19 (partially shown) of quartz or some other suitable high-temperature material is inserted into hole 20.

In operation, a quantity of semiconductor material in powdered form is placed in the areas 16a between the spacer segments 17 and to a suitable height so that, when melted, the semiconductor material will completely fill the areas between the spacer segments 17. A seed crystal 21 is then placed in the area 18 so as to be contacted by the powdered semiconductor material overflowing from the areas 16a. After loading, the boat is placed in a zone-leveler not shown but which is well known in the art. This zone-leveler is preferably the same as described above and takes the form of a quartz tube surrounded by a localized source of heat such as that provided by an induction coil supplied with the output from a radio-frequency generator. The ends of the quartz tube are closed except for inlet and outlet passageways for the flow of an inert gas through the tube and a suitable outlet to permit the quartz rod 19 to extend out of the tube to a suitable boat movement control mechanism. In the alternative, the quartz tube may be constructed so as to move and thus eliminate the quartz rod 19. A coating of carbon on the portions of boat 10 in contact with the semiconductor material has been found to be helpful in preventing adhesion of the semiconductor material to the sides of the boat 10 and spacer segments 17 when the boat is constructed from material other than graphite.

When boat 10 is in position in the zone-leveler, the heat zone produces a molten area at the junction between

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the seed crystal 21 and the powdered semiconductor material thereby reducing it to a molten state. Depending upon whether the crystal is to be of n-type or p-type impurity, suitable impurities are introduced into the molten juncture zone and, after the impurity is melted, the boat is moved in the direction of the arrow by means not shown at a constant rate varying between the ranges of approximately 0.05 inch to 0.20 inch per minute. As the boat moves, the powdered semiconductor material is progressively melted which, upon solidification, assumes the crystalline structure of seed 21 while, by the principles of zone-leveling, the impurity material is uniformly distributed through the semiconductor material in each of the areas 16a.

After boat 10 has completely passed underneath the localized heat zone, the material in the boat is allowed to cool maintaining during this period an inert gas atmosphere in the quartz tube. Upon cooling, the solidified semiconductor material and the spacer segments 17 are lifted or taken as a unit from boat 10 and the spacer segments 17 then removed from between the elongated segments of solidified semiconductor material. The form of the semiconductor material produced by the operation described above is illustrated in Figure 3 and consists of a series of elongated crystal segments 22 attached to the single-crystal 21. Each elongated strip of material 22 is then broken or cut along the line 23 resulting in a flat strip of material, designated as 22a in Figure 4, with a thickness approximating that desired in the crystal segments of completed transistors and diodes. To further approximate the desired thickness for the usable semiconductor elements, the strips 22a are then lapped to within ± 0.003 inch of the final thickness. The strips 22a may then be etched at this point to remove the final ± 0.003 inch of thickness or they may be sectioned into wafers and bars and etched at some later point in the semiconductor device forming operation.

Thus, there has been described a single specific method and embodiment of an apparatus suitable for producing n-type or p-type single crystals of semiconductor material in the form of flat sheets with a thickness approximating that desired for the thickness of the crystal segments used in transistors and diodes. However, it is apparent that further modifications and changes may be made in this method and apparatus without departing from the scope of the invention as disclosed herein. Accordingly, it is the intent of this invention to claim all such modifications and changes as are within the scope of the appended claims.

What is claimed is:

1. A method of initially producing segments of single-crystal semiconductor material of the approximate thickness of the final crystal segments used in the production of semiconductor translating devices comprising the steps of providing compartmented quantities of semiconductor material in contacting relation with a single seed crystal of semiconductor material, producing a molten zone at the juncture of said semiconductor material and said seed by means of a narrow zone of heat, moving said compartmented quantities of semiconductor material and said narrow zone of heat relative to each other, and melting successive portions of the semiconductor material in each compartment whereby the semiconductor material in each compartment assumes the crystal structure of said seed upon solidifying.

2. A method of initially producing segments of impurity-containing, single-crystal semiconductor material of the approximate thickness of the final crystal segments used in the production of semiconductor translating devices comprising the steps of providing compartmented quantities of semiconductor material in contacting relation with a single seed crystal of semiconductor material, producing a molten zone at the juncture of said semiconductor material and said seed by means of a narrow zone of heat, introducing the desired type of impurity

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into said initially molten zone, moving said compartmented quantities of semiconductor material and said narrow zone of heat relative to each other, and melting successive portions of the semiconductor material in each compartment whereby the semiconductor material in each compartment assumes the crystal structure of said seed upon solidifying and contains a uniformly distributed portion of said impurity.

3. A method of initially producing segments of impurity-containing, single-crystal semiconductor material of the approximate thickness of the final crystal segments used in the production of semiconductor translating devices as defined in claim 2 which includes the step of providing compartmented quantities of powdered semiconductor material in contacting relation with a single seed crystal of semiconductor material.

4. A method of initially producing segments of impurity containing, single-crystal semiconductor material of the approximate thickness of the final crystal segments used in the production of semiconductor translating devices as defined in claim 2 wherein said quantities of semiconductor material are each compartmented in a rectangularly shaped form of about 0.002 inch to about 0.025 inch in width.

5. A method of initially producing segments of n-type, single-crystal semiconductor material of the approximate thickness of the final crystal segments used in the production of semiconductor translating devices comprising the steps of providing compartmented quantities of semiconductor material in containing relation with a single seed crystal of semiconductor material, producing a molten zone at the juncture of said semiconductor material and said seed by means of a narrow zone of heat, introducing an n-type impurity into said initially molten zone, moving said compartmented quantities of semiconductor material and said narrow zone of heat relative to each other, and melting successive portions of the semiconductor material in each compartment whereby the semiconductor material in each compartment assumes the crystal structure of said seed upon solidifying and contains a uniformly distributed portion of said n-type impurity.

6. A method of initially producing segments of p-type, single-crystal semiconductor material of the approximate thickness of the final crystal segments used in the production of semiconductor translating

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devices comprising the steps of providing compartmented quantities of semiconductor material in contacting relation with a single seed crystal of semiconductor material, producing a molten zone at the juncture of said semiconductor material and said single seed crystal by means of a narrow zone of heat, introducing p-type impurity into said initially molten zone, moving said compartmented quantities of semiconductor material and said narrow zone of heat relative to each other, and melting successive portions of the semiconductor material in each compartment whereby the semiconductor material in each compartment assumes the crystal structure of said seed upon solidifying and contains a uniformly distributed portion of said p-type impurity.

7. A semiconductor product comprising a plurality of sheet-like segments of semiconductor material connected together at one end by a mass of semiconductor material, all of said semiconductor material being single crystal and grown from a single seed crystal of semiconductor material, said sheets being substantially rectangular in shape and with a thickness of about 0.002 inch to 0.025 inch.

8. A semiconductor product as defined in claim 7 wherein said plurality of segments of single-crystal semiconductor material are of n-type conductivity.

9. A semiconductor product as defined in claim 7 wherein said plurality of segments of single-crystal semiconductor material are of p-type conductivity.

10. A semiconductor product comprising a plurality of sheet-like segments of semiconductor material connected together at one end by a mass of semiconductor material, all of said semiconductor material being single crystal and grown from a single seed crystal of semiconductor material, each of said sheets being of the approximate thickness of the final crystal segments used in the production of semiconductor translating devices.

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