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METHOD OF GROWING A ROD-SHAPED MONOCRYSTAL OF SEMICONDUCTOR MATERIAL BY CRUCIBLE-FREE FLOATING ZONE MELTING

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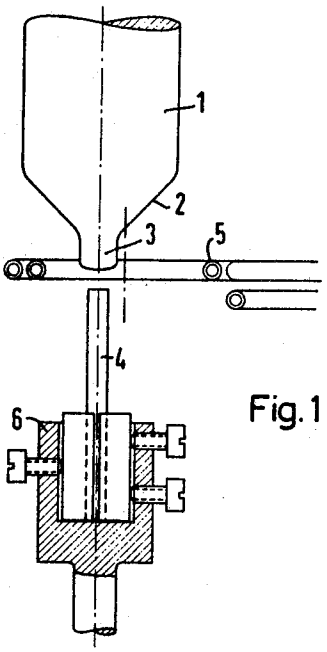


Fig. 1

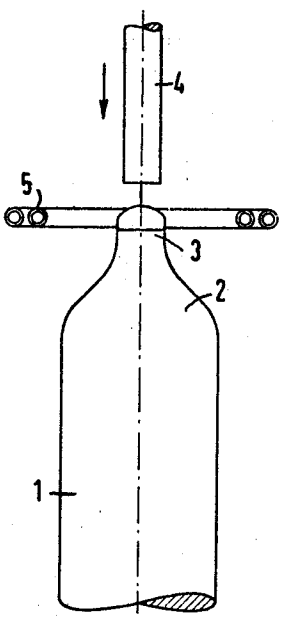


Fig. 2a

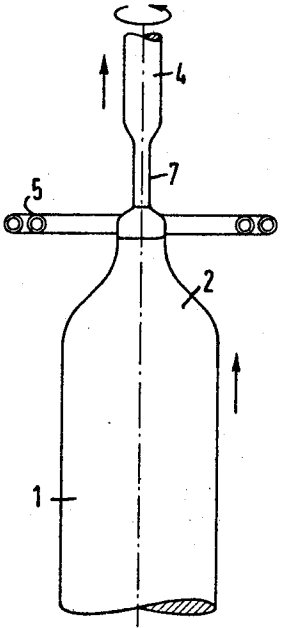


Fig. 2b

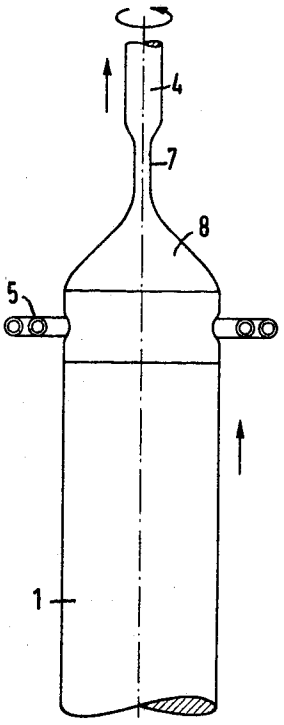


Fig. 2c

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METHOD OF GROWING A ROD-SHAPED MONOCRYSTAL OF SEMICONDUCTOR MATERIAL BY CRUCIBLE-FREE FLOATING ZONE MELTING

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Int. Cl. H01l 7/00
U.S. Cl. 148—1.6 5 Claims

ABSTRACT OF THE DISCLOSURE

Method of growing a rod-shaped monocrystal of semiconductor material by crucible-free floating zone melting a substantially vertically held rod of the material having a nominal diameter greater than 15 mm. includes fusing a seed crystal of the material having a diameter of less than 10 mm. to an end of the rod after reducing the diameter of that end of the rod so that it is at most three times as large as the diameter of the seed crystal, forming a molten zone in the rod at the fused junction thereof with the seed crystal, and passing the molten zone through the rod.

My invention relates to methods of growing a rod-shaped monocrystal of semiconductor material, particularly of silicon, by crucible-free floating zone melting a substantially vertically held rod of the semiconductor material having a nominal diameter greater than 15 mm. to which a thinner polycrystalline seed crystal of the material having a diameter of less than 10 mm. is fused.

Such zone melting methods employing a seed crystal having a thickness which is considerably smaller than the thickness of the semiconductor rod can be employed for producing monocrystalline semiconductor rods that are free of dislocations. Particularly good results, i.e. a high output of dislocation-free monocrystalline semiconductor rods, can be obtained, during a crucible-free zone melting of semiconductor material wherein a melting zone is passed repeatedly through a semiconductor rod, by providing bottleneck-shaped constriction in the semiconductor rod in the immediate vicinity of the junction between the rod and the seed crystal before the last pass of the melting zone through the rod (note the German published application No. 1,079,593).

It has been found that during this just-mentioned known method of growing monocrystalline semiconductor rods, such as dislocation-free monocrystalline semiconductor rods particularly, difficulties arise when the ratio between the semiconductor rod diameter and the seed crystal diameter becomes too great, for example when it exceeds 3:1. Special difficulties are to be expected when the thin seed crystal of, for example, 5 mm. is to be fused to the upper end of a comparatively thick supply rod of semiconductor material having for example, a diameter of 30 mm., for the purpose of growing a monocrystalline semiconductor rod.

It is accordingly an object of my invention to provide a method of growing a rod-shaped monocrystalline semiconductor material by crucible-free floating zone melting which avoids the foregoing difficulties and disadvantages encountered in practicing the method of the aforementioned German published application.

With the foregoing and other objects in view I provide in accordance with my invention in a zone melting operation of the aforementioned type, the step of fusing the seed crystal to an end of the rod after reducing the diameter at the end of the rod either mechanically or chemically or by both methods so that the diameter of the end

of the rod at the junction between the rod and the seed crystal is at most three times as great as the diameter of the seed crystal.

In accordance with another feature of my invention, the reduced-diameter junction end of a rod having a nominal diameter of 25 mm. or more is formed with a cylindrical portion having a diameter that is at least substantially equal to the axial length thereof. This cylindrical portion of the rod end that is reduced in diameter is initially melted and, due to its limited volume, forms a rather small melt which can then be passed through the rod so as to transform it to a monocrystal after the seed crystal has been fused to the reduced end of the rod. In this regard it should be noted that it is completely immaterial whether the end of reduced cross section is located at the top or bottom of the supply rod.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as method of growing a rod-shaped monocrystal of semiconductor material by crucible-free floating zone melting, it is nevertheless not intended to be limited to the details shown, since various modifications may be made therein without departing from the spirit of the invention and within the scope and range of equivalence of the claims.

The methods of the invention, however, together with additional objects and advantages thereof will be best understood from the following description when read in connection with the accompanying drawing, in which:

FIG. 1 is a diagrammatic partly cross-sectional view of apparatus for carrying out one mode of the method of my invention wherein the lower end of the semiconductor supply rod is provided with a diameter of reduced cross section in accordance with my invention; and

FIGS. 2*a* to 2*c* are diagrammatic views of three stages of another mode of the method of my invention wherein the upper end of the semiconductor supply rod is reduced in diameter.

Referring now to the drawings and first particularly to FIG. 1 thereof, there is shown a semiconductor rod **1** which is held at its upper end by a non-illustrated rod holder and which is provided at its lower end with a tapered construction or narrow diameter portion **2** ending in a cylindrical portion **3** having a diameter which is considerably smaller than the nominal diameter of the semiconductor rod **1**. The cylindrical portion **3** of the rod end **2** having reduced diameter has an axial length which is at least as great as the thickness thereof. This insures the fact that when a monocrystalline seed crystal **4** of relatively small diameter is fused to the rod **1** by an inductive heating device such as the heating coil **5**, only the cylindrical portion **3** of the reduced-diameter end **2** of the rod **1** is fused to the seed crystal **4**, while the illustrated tapered conical portion of the end portion **2** remains solid. This greatly facilitates the growth of a monocrystalline semiconductor rod. The seed crystal **4** is clamped in a holder **6** which is advantageously adjustable or spatially orientable. The inductive heating device **5** is in the form of a heating coil having one or more windings which either concentrically or coaxially surround the cylindrical portion **3** of the semiconductor rod **1** or, as shown in FIG. 1, eccentrically surround the cylindrical portion **3**. The eccentric arrangement of the heating coil **5** facilitates the fusing of the cylindrical portion **3** of the semiconductor rod **1** to the seed crystal **4**. After the cylindrical portion **3** has been fused to the seed crystal **4**, the heating coil **5** is then laterally displaced with respect to the axis of the rod **1** so that it is coaxial to the rod **1**. In the illustrated embodiment of FIG. 1, the semiconductor rod **1** has a diameter of 30 mm. or more while the seed

crystal has a diameter of about 4 mm. The cylindrical portion 3 of the rod end 2 of reduced cross section has a diameter between 6 and 9 mm. and an axial length between 6 and 9 mm. The conical tapered portion of the end portion 2 has an apex angle which is at most 90°, i.e. has a peripheral surface which forms at most a 45° angle with the axis of the rod 1. Accordingly, when producing the end portion 2 of reduced diameter by mechanical or chemical erosion or by both, the amount of material that is removed or lost is kept very small as compared with the amount that would have to be removed for an elongated cone. The cylindrical portion 3 of the rod end 2 of reduced diameter can be produced advantageously by fusing a crystalline rod portion of the same semiconductor material to the conical end portion 2 of reduced cross section of the semiconductor rod.

Those elements shown in FIGS. 2*a* to 2*c* which are similar to elements shown in FIG. 1 are identified with the same reference numerals.

In FIG. 2*a* there is shown a seed crystal 4, which is moved downwardly, as indicated by the associated arrow, against the melt formed at the upper end of the cylindrical portion 3 of the rod end 2 of reduced cross section and is fused thereto. The reduced cross section end portion 2 as shown is provided at the free upper end of the semiconductor rod 1. The inductive heating coil 5 is fixed in position and is located concentric to or coaxial with the semiconductor rod 1. After the semiconductor rod 1 and the seed crystal 4 have been fused to one another, they are axially displaced at a speed of about 2.5 mm. per minute relative to the heating coil 5. The axial displacement of the seed crystal 4 with respect to the rod 1 is then continuously increased until the bottleneck-shaped constriction 7 shown in FIGS. 2*b* and 2*c* is formed. At the same time that the seed crystal 4 is axially displaced, it is rotated as shown by the associated curved arrow in FIGS. 2*b* and 2*c*. The thickness of the constriction 7 is about 2.5 mm. and the length thereof about 20 mm. or more. The maximal displacement speed in the axial direction of the seed crystal 4 is more than 20 mm. per minute. As soon as the bottleneck-shaped constriction 7 has the predetermined dimensions mentioned hereinabove for example, the axial displacement speed of the seed crystal 4 is reduced to about 4 to 5 mm. per minute so that the constriction 7 thickens toward the conical transition portion 8. When the recrystallizing rod portion attains its nominal diameter, both the recrystallized rod portion and the supply rod portion are displaced with the same axial speed relative to the heating coil 5. It is advantageous for the volume of the cylindrical portion 3 of the rod end 2 of reduced cross section to be so dimensioned that a bottleneck-shaped constriction 7 of about 2 mm. thickness and at least about 20 mm. length can be pulled therefrom. By the method illustrated in FIGS. 2*a* to 2*c*, dislocation-free monocrystalline semiconductor rods can be produced to a thickness of more than 30 mm.

It is of course quite obvious that the aforedescribed method relating to FIGS. 2*a* to 2*c* can be employed with equally good results in the case where the upper end of the semiconductor rod 1 is clamped in a holder and the end portion 2 having a reduced diameter is located at the lower end of the rod 1 as shown in FIG. 1, for example.

I claim:

1. Method of growing a rod-shaped monocrystal of semi-conductor material by crucible-free floating zone melting a substantially vertically held rod of the material having a nominal diameter greater than 15 mm., which comprises fusing a monocrystalline seed crystal of the material having a diameter of less than 10 mm. to an end of the rod after reducing the diameter of that end of the rod so that it is at most three times as large as the diameter of the seed crystal, forming a molten zone in the rod at the fused junction thereof with the seed crystal, and passing the molten zone through the rod.

2. Method according to claim 1 wherein the rod has a nominal diameter of at least 25 mm., and which comprises forming at least a portion of the rod end of reduced diameter into a cylinder having a diameter that is at least substantially as great as the axial length thereof.

3. Method according to claim 2 wherein the rod has a nominal diameter of at least 30 mm. and the seed crystal has a diameter of about 4 mm., and the rod end portion of reduced diameter is formed with a conical transition portion having an apex angle of at most 90° ending in the cylindrical portion, the cylindrical portion having a diameter of between 6 and 9 mm. and an axial length of between 6 and 9 mm.

4. Method according to claim 1 wherein the rod has a nominal diameter of at least 25 mm., and which comprises fusing a crystalline cylindrical rod portion of the material having a smaller diameter than the nominal rod diameter to the end of the rod to form at least part of the reduced-diameter end thereof, the cylindrical rod portion having a diameter that is at least as great as the axial length thereof.

5. Method according to claim 1 wherein at least a part of the reduced-diameter end portion of the rod is cylindrical and is of predetermined volume for pulling a bottleneck-shaped constricted portion of about 2 mm. thickness and about 20 mm. length therefrom.

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