Dec. 3, 1968 W. KELLER 3,414,388
METHOD AND APPARATUS FOR INCREASING THE CROSS SECTION OF
A CRYSTALLINE ROD DURING CRUCIBLE-FREE ZONE MELTING
Original Filed Jan. 29, 1965 2 Sheets-Sheet 1

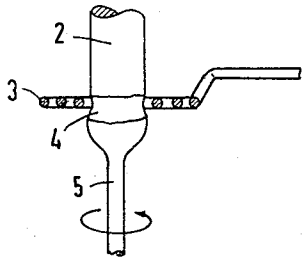


Fig. 1

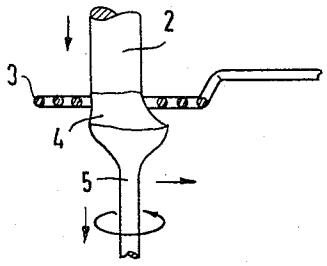


Fig. 2

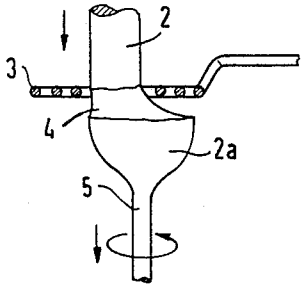


Fig. 3

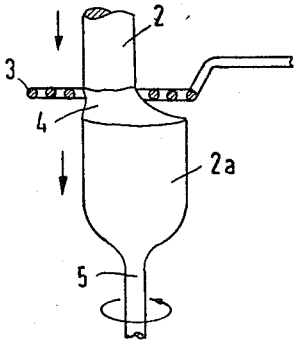


Fig. 4

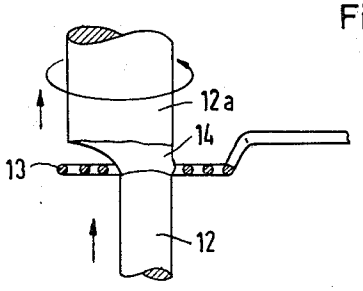


Fig. 5

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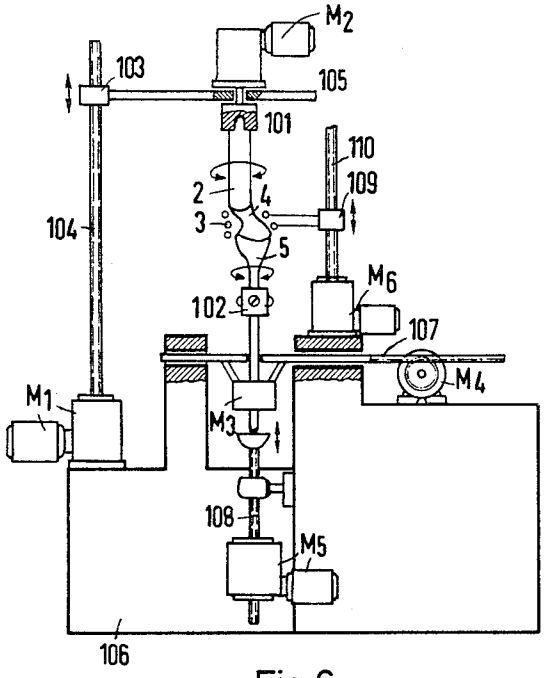


Fig.6

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3,414,388

METHOD AND APPARATUS FOR INCREASING THE CROSS SECTION OF A CRYSTALLINE ROD DURING CRUCIBLE-FREE ZONE MELTING

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Continuation of application Ser. No. 428,933, Jan. 29, 1965. This application Aug. 29, 1967, Ser. No. 664,211
Claims priority, application Germany, Feb. 1, 1964, S 89,317
8 Claims. (Cl. 23—301)

ABSTRACT OF THE DISCLOSURE

A semiconductor rod fixed at both ends by end-holders, at least one of which is mounted for rotation is zone refined by a traversing annular heater. The rod end-holders are displaceable relative to each other and transverse to the vertical axis of the rod.

This application is a continuation of application Ser. No. 428,933, now abandoned.

My invention relates to crucible-free zone melting method and apparatus and particularly to method and apparatus for increasing the cross section of a rod-shaped body of crystalline substance, particularly of semiconductor substance, during crucible-free or floating zone melting.

Methods of this type generally are carried out with a rod-shaped body of the material clamped at both ends and held in vertical position. A heating device produces a molten zone along a narrow axial length of the rod and by the relative motion of the heating device and the rod, the molten zone is passed over the length of the rod. Zone melting thus serves in most cases to refine the material and also to convert a polycrystalline rod into a monocrystalline rod with the aid of a crystal seed fused to one end of the rod.

Zone melting apparatus of the general type illustrated and described in U.S. Patents No. 2,972,525; No. 2,992,311 and No. 3,030,194, for example, may be adapted to the invention of this application.

It is an object of my invention to improve the existing zone melting methods and apparatus and more particularly to improve the known methods and apparatus so as to obtain a rod-shaped body of crystalline substance of greater cross-sectional dimension than heretofore possible with similar apparatus and methods.

With this end in view and in accordance with a feature of my invention, I provide a method which comprises relatively moving the end holders of the crystalline rod toward one another, applying heat to the crystalline rod intermediate the end holders thereof by a heating ring surrounding the rod so as to form a molten zone therein, and passing the molten zone longitudinally along the rod, the displacement of the holders toward one another and the movement of the molten zone along the rod being at such relative speeds that the diameter of the rod portion freezing from the melt is increased so that it is greater than the diameter of the heating ring surrounding the rod, and rotating at least one of the rod end holders about the longitudinal axis of the rod.

In accordance with a further aspect of my invention, at the beginning of the operation both holders are located in the same vertical axis, then one end holder, with respect to the second end holder and to the heater, is successively shifted sidewise and upwardly, whereby the cross section of the rod portion held by this first-mentioned end holder is increased, and after the desired cross section is achieved, the first-mentioned end holder is displaced only upwardly with respect to the heater.

The method of my invention has the particular advantage that operating in the vicinity of the transition from the original cross section to the newly enlarged cross section is essentially facilitated. Furthermore, it is possible with my invention to produce semiconductor rods with greatly enlarged cross section than was possible with the methods known heretofore. Furthermore, it is possible to locate the end holder of the rod, whose cross section is to be enlarged, above the heater.

The apparatus of my invention includes particularly the feature of means for displacing one of the rod end holders in a substantially horizontal direction while rotating the same so that the rod portion located between the one rod end holder and the molten zone is formed with a specific diameter larger than the inner diameter of the heating ring.

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 and apparatus for increasing the cross section of a rod-shaped crystalline substance, particularly semiconductor substance, during crucible-free zone melting, it is nevertheless not intended to be limited to the details shown, since various modifications and changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

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

FIGS. 1 to 4 are elevational views partly broken away and partly in section showing various phases during the carrying out of the method of the invention;

FIG. 5 is an elevational view, partly broken away and partly in section, showing a phase comparable to that of FIG. 4 during the carrying out of another form of the method of this invention; and

FIG. 6 is a schematic view of apparatus for carrying out the method of my invention.

Referring now to the drawings and particularly to FIG. 1 thereof, there is shown a semiconductor rod **2** in which, by means of an induction heating coil **3**, energized with a high frequency current, a melting zone **4** is produced. The seed crystal **5**, which can consist, for example, of a monocrystal, is fused at the lower end of the rod **2** and serves to promote monocrystalline growth. The seed crystal **5** and the lower rod portion therewith are set in rotation about the vertical axis by, for example, driving the lower rod holder with an electric motor (FIG. 6). As shown in the drawing, the melting zone, at the instant represented in FIG. 1, has reached the point at which the transition from the thin seed crystal to the normal rod thickness is achieved.

In FIG. 2, the further steps of the method of my invention are represented in a later stage by means of suitable arrows. The seed crystal **5** is not only displaced downwardly with respect to the heating coil **3** which is assumed to be at rest, but is also simultaneously displaced toward the right-hand side in the plane of the drawing. The melting zone **4** is thereby stretched toward the right also. Since the lower rod portion rotates about its own axis, the material crystallizing from the melt grows essentially symmetrical to the rotary axis of the lower rod holder. The upper rod portion **2** is shifted downwardly from above at a suitable rate.

A further phase of the method of my invention is shown in FIG. 3. By displacing the seed crystal **5** toward the right-hand side of FIG. 3, further growth of the rod diameter of the lower rod portion **2***a* is obtained.

Finally in FIG. 4 the solid end state or final condition of the method of my invention is achieved, in that no further lateral displacement of the lower rod portion **2***a* is carried out, but rather the rod portions **2** and **2***a* are displaced only downwardly with their holders. It can be assumed, for example, that the rod will be increased to double its diameter so that consequently the cross-sectional area of the rod is quadrupled. In this case, with respect to the heating coil **3**, the upper rod portion **2** must be fed downwardly with four times the speed at which the lower rod portion **2***a* is drawn away from the heating coil. One can, therefore, for example, assume that the lower rod portion **2***a* is displaced downwardly with a speed of 2 mm. per minute whereas the upper rod portion **2** is displaced downwardly with a speed of 8 mm. per minute. The rotary speed of the lower rod portion can be approximately 5 to 100 r.p.m., advantageously about 20 r.p.m.

The transition of the melting zone from thin seed crystal to the phase or condition represented in FIG. 4 requires particular attention on the part of those entrusted with the operation. Thus the gradual increase in speed at which the upper rod portion **2** is fed downwardly must be accompanied with a simultaneous increase in the heating capacity supplied to the coil **3**.

In FIG. 5 there is shown another embodiment wherein the rod portion **12***a*, which has been enlarged by displacing the upper end holder of the rod toward the left-hand side of the figure, is located above the heating coil **13**. The rod portions **12** and **12***a* are displaced upwardly with respect to the heating coil **13**. The melting zone **14** can be maintained at the upper rod portion **12***a* due to the large adherent surface, if it is of particularly small dimension in the direction of the rod axis. Heating by means of a flat induction coil with spirally arranged windings can consequently be employed with particular advantage in such a case.

FIG. 6 is a diagrammatic view of apparatus for carrying out the method of the invention.

A rod comprising an upper rod portion **2** and a lower seed crystal portion **5** is virtually supported by the end holders **101**, **102**. A slider **103**, displaceable on a rotary spindle **104**, has an extension **105** abutting the holder **101** so as to be able to displace the holder **101** and the rod portion **2** in either vertical direction depending on the direction of rotation of a reversible motor M_1. A reversible motor M_2 is supported on the extension **105** for rotating the holder **101** and the rod portion **2**. The motor M_1 is supported on a base **106** of the apparatus. The holder **102** of the seed crystal is rotatable by a motor M_3 which has a displaceable shaft at one end of which the holder **102** is secured. The motor M_3 is fastened to a slide **107** which is horizontally displaceable by a rack and pinion mechanism driven by a motor M_4 mounted on the base **106** whereby the holder **102** and the seed crystal **5** are displaceable in a direction transverse to the vertical axis of the rod. A motor M_5, also mounted on the base **106**, drives a rotary spindle **108** provided with a spindle head that is in engagement with the displaceable shaft of the motor M_3 for vertically displacing the holder **102** and the seed crystal **5** being formed into a lower rod portion. The horizontal displacement distance of the seed crystal **5** and the holder **102** is relatively small so that the relatively wide abutting surface of the head on the spindle **108** engages the displaceable shaft of motor M_3 in all of the possible horizontally displaced positions of the slide **107** and the motor M_3 secured thereto. An induction heating coil **3**, preferably with a flat winding surrounds and is spaced from the molten zone **4** of the rod portion **2** and is vertically displaceable by a slider **109** and a rotary spindle **110** driven by a motor M_6 which is mounted on the base **106**.

Of course, as in accordance with the apparatus described in Patents Nos. 2,972,525, 2,992,311 and 3,030,194, the apparatus of my invention is located in a vacuum or protective gas atmosphere.

I claim:

1. In a process of zone melting a semiconductor rod wherein the rod is vertically supported at its ends by end holders located in the vertical axis of the rod, one of the end holders being rotatable about the vertical axis, and a molten zone is formed in the rod by an annular heating device surrounding and spaced from the rod, the end holders being relatively movable in a direction toward one another, and the heating device being displaceable along the rod so as to pass the molten zone along the rod, the improvement which comprises displacing one of the end holders in a direction transverse to the vertical axis of the rod and the annular heating device so that the axes of the end holders are displaced laterally relative to one another.

2. Process according to claim **1**, which comprises also displacing the one end holder in a vertical direction, and rotating the one end holder until the rod portion located between the rotatable one end holder and the molten zone is formed to a specific cross section, then, after forming the rod portion to the specific cross section, displacing the one end holder in a vertical direction away from the heating device.

3. Process according to claim **1**, wherein the lower one of the end holders is rotatable, and which comprises displacing the lower end holder in a direction transverse to the vertical axis of the rod and the annular heating device, displacing the lower end holder also in a vertically downward direction, and rotating the lower end holder until the lower rod portion located between the lower end holder and the molten zone is formed to a specific cross section, and then, after forming the lower rod portion to the specific cross section, displacing the lower end holder only in a vertically downward direction away from the heating device.

4. Process according to claim **1**, wherein the upper one of the end holders is rotatable, and which comprises displacing the upper end holder in a direction transverse to the vertical axis of the rod and the annular heating device, displacing the upper end holder in a vertically upward direction, and rotating the upper end holder until the upper rod portion located between the upper end holder and the molten zone is formed to a specific cross section, and then, after forming the upper rod portion to the specific cross section, displacing the upper end holder only in a vertically upward direction away from the heating device.

5. Apparatus for zone melting a semiconductor rod comprising vertically aligned end holders supporting between them a vertically extending semiconductor rod, means for relatively displacing said end holders toward one another, an annular heating device surrounding and spaced from the rod, said heating device forming a molten zone in the rod, means for displacing said heating device along the rod so as to pass the molten zone along the rod, means for rotating at least one of said end holders, and means for displacing said one end holder in a direction transverse to the axes of said rod.

6. Apparatus according to claim **5**, wherein said one end holder is the lower one of the vertically aligned end holders.

7. Apparatus according to claim **5**, wherein said one end holder is the upper one of the vertically aligned end holders.

8. Apparatus according to claim **5**, wherein said heating device is a flatly wound induction coil for forming a melting zone of relatively small thickness in the longitudinal direction of the rod.

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