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ADVANCE MELT ZONE PRODUCTION OF A MONACRYSTALLINE ROD

Filed Sept. 22, 1967

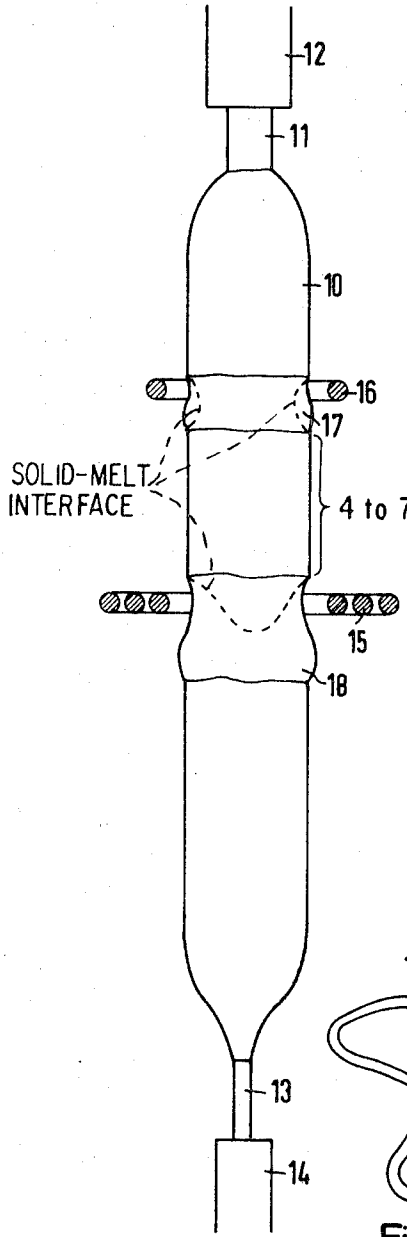


Fig.1

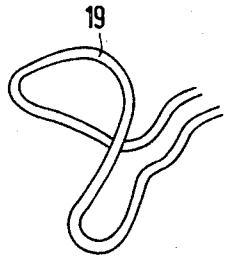


Fig. 3

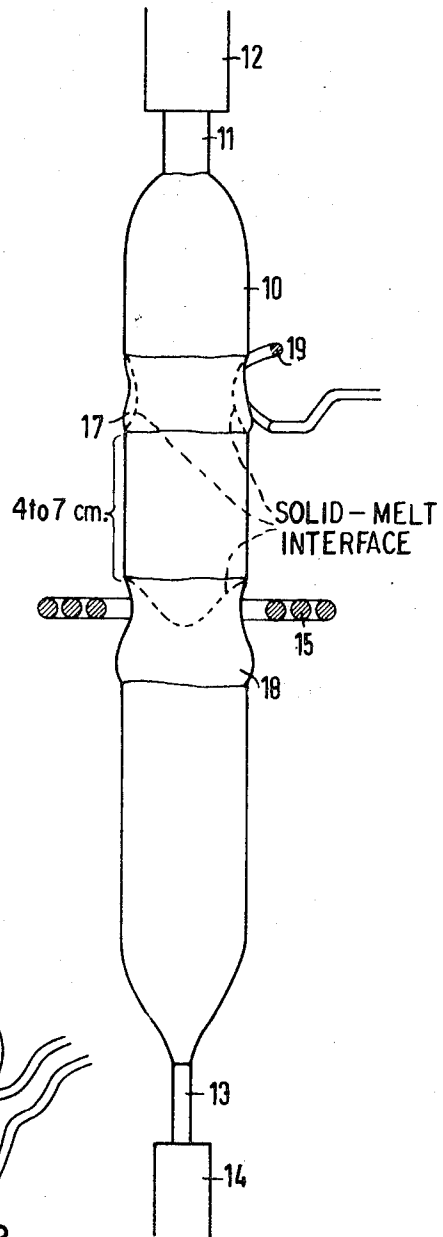


Fig.2

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ADVANCE MELT ZONE PRODUCTION OF A MONOCRYSTALLINE ROD

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U.S. Cl. 23—301 9 Claims

ABSTRACT OF THE DISCLOSURE

Method of crucible-free zone melting a crystalline rod which comprises successively passing along the rod in the axial direction thereof an advance melting zone formed in the rod to a depth smaller than the radial thickness of the rod and a subsequent melting zone formed in the rod and extending across the entire cross section of the rod.

Our invention relates to method of crucible-free zone melting a crystalline rod, especially of semiconductor material.

It is known to transform polycrystalline rods into rod-shaped monocrystals by fusing a monocrystalline seed crystal to one end of a polycrystalline rod, and to pass a melting zone repeatedly through the crystalline rod starting from the fused junction of the seed crystal therewith. This zone-melting process is frequently carried out without a crucible, i.e. a melting zone produced with the aid of a high frequency heating coil surrounding the rod is passed through the crystalline rod, which is vertically disposed between a pair of rod end-holders. The end holders can be rotated in the same or opposite rotary directions.

To save time and energy, an effort is usually made to transform the polycrystalline rod to a monocrystal by at most a single melting zone pass through the rod. Difficulties are sometimes encountered thereby because entire granules can become loosened at the edge of the boundary surface or interface between the polycrystalline rod and the melting zone when the polycrystalline material is being melted, and those loosened granules can then find their way without melting to the boundary surface between the melting zone and the rod portion solidifying or recrystallizing from the melting zone and can cause disturbance of the monocrystal formation at that location. An additional melting zone pass through the rod is then necessary in order to obtain complete formation of the monocrystal.

It is accordingly an object of our invention to provide method of crucible-free zone melting a crystalline rod which avoids the foregoing disadvantage of previously known methods of this general type and which, more particularly, avoids disturbance of monocrystal formation by non-melted particles.

With the foregoing and other objects in view, we accordingly provide method of crucible-free zone melting a crystalline rod which comprises successively passing along the rod in the axial direction thereof an advance melting zone formed in the rod to a depth smaller than the radial thickness of the rod and a subsequent melting zone formed in the rod and extending across the entire cross section of the rod.

In accordance with further features of our invention, the advance melting zone is annular in shape and has a depth of from ⅕ to ⅔, and preferably ½, the radius of the rod. In one mode of the method of our invention, both melting zones are passed together through the rod, the advance melting zone travelling in advance of the subsequent melting zone spaced at a predetermined distance

therefrom. It is advantageous when the melting zones are mutually spaced apart a distance of from 4 to 7 cm.

In another mode of the method of our invention, an advance melting zone is first passed through the entire rod and, thereafter, the subsequent melting zone is passed through the 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 crucible-free zone melting a crystalline rod, it is 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 equivalence of the claims.

The method of the invention, 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 and 2 are longitudinal views of a crystalline rod and two embodiments of a device for crucible-free zone melting the rod in accordance with our invention; and

FIG. 3 is a perspective view of a component of the device of FIG. 2.

Referring now to the drawings and first, particularly, to FIG. 1 thereof, there is shown a crystalline rod **10**, for example of silicon, vertically supported in a device for crucible free zone melting the rod **10**. At the upper end of the rod **10**, as viewed in FIG. 1, a carbon rod **11** is fused thereto and is secured in a holder **12**. At the lower end of the rod **10**, as viewed in FIG. 1, a narrow monocrystalline seed crystal **13** is fused thereto and is secured in a holder **14**. The rod **10** is surrounded by two high frequency heating coils **15** and **16** which are connected to a common high frequency electrical generator (not shown) or to two different high frequency generators (not shown). The spacing between the coils **15** and **16** is such that the melting zones produced thereby in the rod **10** are located about 4 to 7 cm., and preferably 5 cm., from one another.

To carry out the method of the invention, the rod **10** is moved in the axial direction thereof relatively to the high frequency coils **15** and **16** a distance until the high frequency coil **16** surrounds the carbon rod **11**. Then the high frequency coil **16** is electrically energized so that an incandescent zone is formed in the carbon rod **11**. This incandescent zone is then passed by relative motion of the colis **15** and **16**, on the one hand, and the rod **10**, on the other hand, through the rod **10** to the location at which the seed crystal **13** is engaged with the rod **10**. As soon as the incandescent zone has reached the location of contact between the seed crystal **13** and the rod **10**, the electrical energy supplied to the coil **16** is increased so that the rod material melts and an annular advance melting zone **17** is formed below the surface of the rod. By relative motion between the rod **10** and the coils **15** and **16**, the annular advance melting zone **17** is passed through the rod in a direction from the lower to the upper end thereof, as viewed in FIG. 1. The depth of the annular advance melting zone **17** is from ⅕ to ⅔ the radial thickness of the rod **10**, a depth of ½ the rod radius being most favorable. When the coil **15** has reached the location of engagement between the seed crystal **13** and the rod **10**, the relative motion between the rod **10**, on the one hand, and the coils **15** and **16**, on the other hand, is interrupted, and electrical energy is supplied to the coil **15**. After the seed crystal **13** has been fused to the rod **10**, the relative motion is continued in the same direction and the subsequent melting zone **18**, produced by means of the coil **15** and extending over the entire cross section

of the rod **10**, is passed together with the annular advance melting zone through the rod **10**. The formation of the monocrystal is accordingly free of trouble, because the granular polycrystalline structure, which might otherwise cause disturbances, is homogenized by the advance melting zone below the surface of the rod.

The high frequency coil **16** producing the annular advance melting zone **17** is de-energized shortly before it reaches the carbon rod **11**.

A wire loop **19**, is shown in partial sectional view in FIG. and in perspective in FIG. 3, also energized with high frequency current but not surrounding the crystalline rod **10**, can also be used for producing an advance melting zone in the rod **10**. The wire loop **19** is located alongside the semiconductor rod **10**, for example in a curved plane parallel to the surface of the rod **10**. The rod holder **12** and the upper polycrystalline rod portion held thereby, as shown in FIG. 2, must then be rotated so that the entire peripheral surface of the rod portion at the particular level of the wire loop **19** sweeps past the loop and is heated thereby. The relative motion of the rod **10**, on the one hand, and the high frequency coil **15** as well as the wire loop **19**, on the other hand, is effected in such a way that the material of the rod **10** first passes the wire loop **19**. In other words, for example, as viewed in FIG. 2, the rod **10** can either be moved upwardly while the loop **19** and coil **15** are held stationary, or the rod **10** can be held stationary while the loop **19** and the coil **15** are moved upwardly in succession along the rod **10**.

If the monocrystalline seed crystal in the devices of FIGS. 1 and 2 were clamped in the upper rod holder i.e. the monocrystalline re-solidifying rod were being pulled downwardly from above, then the high frequency coil **16** or the wire loop **19** producing the advance melting zone must be disposed below the high frequency coil **15** producing the subsequent melting zone.

It is advantageous to energize the high frequency coils **15** and **16** and the wire loop **19** with two different high frequency generators. Thus, neither the supply of electrical energy to the high frequency coil **15** nor the supply of electrical energy to the high frequency coil **16** or the wire loop **19** can affect one another.

In a further modification of the invention, only a single high frequency coil **15** can be used in the device of FIG. 1. In such a case, the crystalline rod **10** and the high frequency coil **15** are initially displaced in the axial direction relative to one another for a distance until the high frequency coil **15** surrounds the carbon rod **11**. The high frequency coil **15** is then energized, and an incandescent zone is formed in the carbon rod **11**. The incandescent zone is then passed into the rod material adjoining the carbon rod **11** by relative motion between the high frequency coil **15** and the crystalline rod **10** in the axial direction of the rod **10**. Thereafter, the supply of electrical energy to the high frequency coil **15** is increased so that an annular advance melting zone is formed below the surface of the crystalline rod **10**. The advance melting zone is then passed by a further relative motion of the coil **15** and the rod **10** in the axial direction thereof through the crystalline rod **10** to the location at which the rod **10** engages the seed crystal. The seed crystal **13** is then fused by the coil **15** to the rod **10** and, thereafter, the electrical energy supplied to the high frequency coil **15** is again increased and a subsequent melting zone extending over the entire cross section of the rod **10** is produced by the coil **15** and is passed through the rod **10** by relative motion of the rod **10** and the coil **15** in the opposite direction.

As aforementioned, the relative movements in the axial direction of the rod **10** can be effected either by displacing the high frequency coils **15** and **16** and the wire loop **19** while the crystalline rod **10** is held stationary or by displacing the crystalline rod **10** while maintaining the high frequency coils **15** and **16** and the wire loop **19** stationary.

Although not shown in the drawing, the device according to our invention is installed in an evacuated vessel or in a vessel containing an inert atmosphere such as argon, for example. Auxiliary equipment for carrying out a crucible-free zone melting process in accordance with the invention are not shown since they are not essential to the method of the invention and are, moreover, well known to the man of ordinary skill in the art of zone melting.

We claim:

1. Method of crucible-free zone melting a crystalline rod so as to transform it into a monocrystalline rod, which comprises successively passing along the rod in the axial direction thereof from a monocrystalline seed crystal fused to an end of the rod an annular advance melting zone formed in the rod to a uniform depth smaller than the radial thickness of the rod and a subsequent melting zone formed in the rod and extending across the entire cross section of the rod.

2. Method according to claim **1** wherein the advance melting zone has a depth of ⅕ to ⅔ the radial thickness of the crystalline rod.

3. Method according to claim **1**, which comprises passing both melting zones, spaced apart from one another a distance of substantially 4 to 7 cm., simultaneously through the rod.

4. Method according to claim **1**, which comprises passing both melting zones simultaneously through the rod.

5. Method according to claim **1**, which comprises initially passing the advance melting zone through the entire rod and thereafter passing the subsequent melting zone through the rod.

6. Method according to claim **1**, which comprises relatively displacing, in the axial direction, the crystalline rod and a pair of coaxially spaced high frequency coils surrounding the rod and energized at different intensities to form the respective melting zones therein, so that the material of the rod first passes the coil energized at lower intensity.

7. Method according to claim **6**, which includes separately energizing the high frequency coils from respective generators.

8. Method according to claim **1**, which comprises relatively displacing in the axial direction the crystalline rod, on the one hand, and an energized high frequency coil surrounding the rod as well as a wire loop axially spaced from the coil and located adjacent the rod, on the other hand, the loop being energized at lower intensity than the coil, so that the material of the rod first passes the wire loop, and simultaneously rotating the part of the material first passing the wire loop.

9. Method according to claim **1**, which comprises relatively displacing in the axial direction the crystalline rod and a high frequency coil surrounding the rod and energizable at varying intensity, while the coil is energized at a relatively low intensity, and thereafter increasing the intensity of the energy supplied to the coil and relatively displacing the rod and coil in the opposite axial direction while the coil is energized at the increased intensity.

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