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3,310,384

METHOD AND APPARATUS FOR CRUCIBLE-FREE ZONE MELTING

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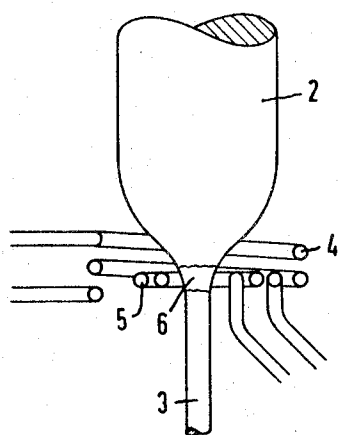


Fig. 1

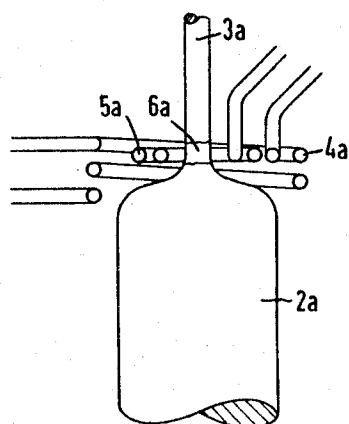


Fig. 2

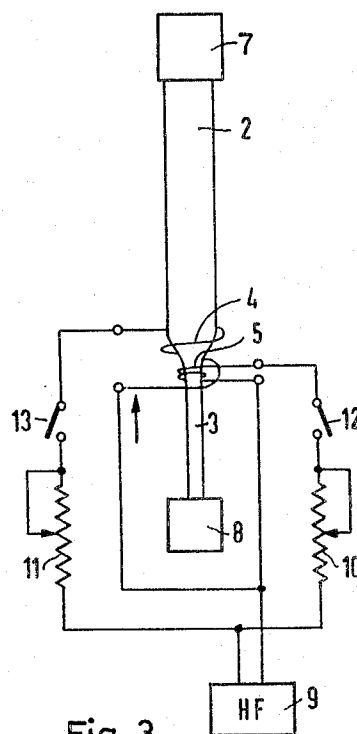


Fig. 3

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METHOD AND APPARATUS FOR CRUCIBLE-FREE ZONE MELTING

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4 Claims. (Cl. 23—301)

My invention relates to method and apparatus for crucible-free or floating zone melting of a semiconductor rod held at both of its ends in a substantially vertical attitude.

It is, of course, well known that there are many methods and apparatuses for crucible-free zone melting. In these methods and apparatuses for carrying out the methods generally a semiconductor rod is held vertically by being clamped at its ends inside a vessel that is evacuated or filled with protective gas. A heating device surrounding the rod serves for melting a short length of the rod, the so-called melting zone. By suitably providing relative displacement between the rod which is to be processed and the heating device, the melting zone is passed over the entire length of the rod. An induction heating coil has proved itself to be particularly successful as the heating device, since by its use the necessary heating power can be applied to the melting zone without danger of contamination due to contact or the like therewith.

It is also known in these methods and apparatuses for crucible-free zone melting to set a seed crystal at one end of the semiconductor rod, the cross section of the seed crystal being considerably smaller than that of the rod that is being processed. In this manner, the quality of the monocrystal that is formed, especially with regard to the dislocation density, can be improved.

During the processing of semiconductor rods with relatively large cross sections, for example with a cross section of more than 30 mm. diameter, difficulties arise particularly if a relatively narrow seed crystal is to be fused thereto. If the diameter of the rod is enlarged beyond a specific value, the melting zone has a very strong tendency to drip off and thereby interrupt the process. This is particularly the case when the induction heating coil is energized, as is customary at times, with current of frequencies of about 3 to 5 megacycles. In this case, namely, the supporting effect of the electromagnetic field, which acts as a shape-forming force, is relatively small. With semiconductor rods of small diameter, this force is completely sufficient. However, with larger rod diameters, it is not strong enough so that the melting zone is not always prevented from leaking away. If, on the other hand, the induction heating coil is energized with currents of lesser frequency, for example of 500 to 1500 kilocycles, the supporting effect is consequently greater. However, the heating effect on the other hand is less and particularly when greater clearances or spacings are to be overcome. In most cases, this then leads to a situation where the heating effect is no longer sufficient for melting the seed crystal at the fusing location.

It is accordingly an object of my invention to provide method and apparatus for crucible-free zone melting which overcome the aforementioned difficulties of the known methods and apparatuses while permitting the use of currents of suitable frequency.

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With this and other objects in view, I provide method and apparatus for crucible-free zone melting of a rod formed of crystalline material, such as semiconductor material like silicon especially, with the aid of an induction heating coil surrounding the rod and energized with high frequency alternating current and movable relative to the rod in the direction of the longitudinal axis thereof. The seed crystal is attached at one end of the rod and has a cross section considerably smaller than that of the rod. A second induction heating coil is provided by means of which the seed crystal is first melting at the junction thereof with the rod and then the melting zone is passed with the aid of the first-mentioned induction heating coil over the entire length of the rod. By employing a second induction heating coil, it is then possible to accurately adjust the inner diameter of the heating coil employed for the respective intended purpose.

The apparatus for carrying out the method of my invention therefore comprises two induction heating coils of which the first coil has an inner diameter which is only slightly larger than the outer diameter of the rod that is to be processed, and the second heating coil has an inner diameter which is only slightly larger than the outer diameter of the seed crystal. In most cases it is sufficient that only the first induction heating coil be displaceable relative to the semiconductor rod. The second heating coil which serves only for fusing the seed crystal or the fusion location of the seed crystal is required only to be displaceable over a small portion of the rod length or not displaceable at all.

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 crucible-free zone melting, it is nevertheless not intended to be limited to the details shown, since various modifications and structural 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 construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a diagrammatic view of apparatus used in conjunction with a crystalline rod that is to be processed and to the lower end of which a seed crystal is fused;

FIG. 2 is a diagrammatic view of a second embodiment of the apparatus of FIG. 1 as used with a crystalline rod having a seed crystal fused to the upper end thereof, and

FIG. 3 schematically shows the apparatus of FIG. 1 in conjunction with an appertaining power supply circuit.

Referring now to the drawings and first particularly to FIG. 1, there is shown a semiconductor rod 2, consisting for example of silicon and having a diameter of about 40 mm., to which a seed crystal 3 having a diameter of 6 mm. is fused. For heating the melting zone, which is to pass along the semiconductor rod 2, there is provided an induction heating coil 4 shaped as a flat cylindrical coil. The inner diameter of the heating coil 4 is adjusted to the diameter of the semiconductor rod 2, that is, it is only slightly larger, for example 2 mm. larger, than the diameter of the rod that is to be proc-

essed. Within this heating coil 4 there is located a second induction heating coil 5 which is shaped, in the embodiment shown in FIG. 1, as a helically wound flat coil. With the aid of the induction heating coil 5, the melting zone 6 which is to be formed at the starting location of the seed crystal is produced at the beginning of the process. The semiconductor rod 2 is advantageously processed beforehand, for example by being conically ground or shaped and tapering in a direction toward the seed crystal 3.

FIG. 3 shows schematically a circuit diagram for operating an apparatus as shown in FIG. 1. The semiconductor rod 2 and seed crystal 3 are clamped at their extreme ends in respective holders 7 and 8 which are fixedly mounted. The coil 4 is mounted so that it is displaceable with respect to the coil 5 along the rod 2 for passing the melting zone upwardly along the rod. The coil 4 may, if desired, be movable slightly in a downward direction. The coil 4 is energized for example from a high-frequency current generator 9 through an adjusting resistor 11, and the coil 5 is connected, for example, to the same generator 9 through a control resistor 10. Switches 12 and 13 are provided for respectively deenergizing the coil 5 after the melting zone is formed and energizing the coil 4 at that time.

In all other respects, the zone-melting apparatus may correspond to those known from U.S. Patents No. 2,972,525, No. 2,992,311 and No. 3,030,194, for example.

Thus, after the melting zone is formed with the aid of the induction heating coil 5, the induction heating coil 4 is connected to a suitable current source, for example the high frequency generator 9 producing current at a frequency of 1.5 megacycles, whereupon the induction heating coil 5 can be switched off by opening the switch 12. After the melting zone is namely first produced, the induction heating coil 4 can also be coupled to the melting zone in spite of the greater spacing. On the other hand, the possibility does not often exist of a coupling therebetween as long as the material to be processed is solid, for example, in the case of semiconductor rods which are mostly considered to be insulators in the cold state. After the heating coil 5 is switched off, the melting zone is displaced upwardly due to relative motion of the heating coil 4 and the rod 2. Heating coil 5 can be displaced downwardly beforehand out of the field of the heating coil 4 whereby the observation of the melting zone is improved. The heating coil 5 need be displaceable only very slightly for this, for example, it need be capable of being displaced over a distance of, for example, only 10 mm. along the rod axis. The heating coil 5 can, however, also if necessary be simply left at its original location since it can no longer be electrically operable there. The leads to the heating coil 5 can, for example, simply be left open or unconnected whereby a coupling of the coil 5 with the coil 4 can be safely avoided. Also, if necessary, suitable capacitors can be connected in parallel whereby detuning of the heating circuit of the coil 5 with respect to the heating circuit of the coil 4 is achieved.

After the coil 5 is switched off, the coil 4 is then displaced upwardly in the direction of the arrow (FIG. 3) so that the melting zone 6 is also displaced in an upward direction. Consequently, the heating power supplied to the coil 4 is increased so that greater amounts of the semiconductor material can be melted whereby the melting zone is increased with respect to the increasing diameter. In this manner, the melting zone 6 can be passed upwardly through the entire rod 2 with the result that the heating power is so greatly reduced that only a glowing zone remains in existence which is then displaced downwardly due to the relative motion of the heating coil 4. The new melting of the melting zone can, if necessary, be produced by the heating coil 4 alone. However, heating can also be provided either additionally with or solely by the induction heating coil 5 in order to produce the new melting zone.

In FIG. 2 there is shown another embodiment of the apparatus shown in FIG. 1 in which a seed crystal is located at the upper end of the vertically oriented semiconductor rod which is to be processed rather than the lower end thereof. It has been found to be desirable in many cases with larger rod diameters to provide for the movement of the melting zone in a direction from an upper to a lower position. Those elements shown in FIG. 2 which correspond to the elements shown in FIG. 1 are identified with the same reference numerals as in FIG. 1 with the addition of the letter *a*. It is of course clearly evident that the man of ordinary skill in the art may readily adapt the embodiment of FIG. 2 to the operating circuit of FIG. 3.

I claim:

1. Method of crucible-free zone melting a vertically mounted crystalline rod of relatively large diameter joined at one end to a seed crystal of relatively small diameter and coaxially surrounded by a radially spaced pair of induction coils at the junction of the rod and the seed crystal, which comprises energizing a first induction coil radially closer to the junction for heating the seed crystal to a temperature at which a melting zone is formed at the junction therein and the seed crystal is fused to the rod, deenergizing the radially closer induction coil and simultaneously energizing a second induction coil radially more distant from the junction for applying heat to substantially the same junction area to maintain it in molten state, and relatively displacing the rod and the radially more distant induction coil in the longitudinal direction of the rod for passing the melting zone along the rod.

2. Apparatus for crucible-free zone melting a vertically mounted crystalline rod of relatively large diameter joined at one end to a seed crystal of relatively small diameter, comprising a first induction coil surrounding the seed crystal at its junction with the rod and having an inner diameter only slightly larger than the diameter of the seed crystal, said first induction coil being energizable for heating the seed crystal to a temperature at which a melting zone is formed therein and the seed crystal is fused to the rod, and a second induction coil coaxial to and surrounding said first induction coil, said second induction coil having an inner diameter slightly larger than the diameter of the rod and being energizable for applying heat to the melting zone so that it is maintained in molten state.

3. Apparatus for crucible-free zone melting a vertically mounted crystalline rod of relatively large diameter joined at one end to a seed crystal of relatively small diameter, comprising a first induction coil surrounding the seed crystal at its junction with the rod and having an inner diameter only slightly larger than the diameter of the seed crystal, said first induction coil being energizable for heating the seed crystal to a temperature at which a melting zone is formed therein and the seed crystal is fused to the rod, and a second induction coil coaxial to and surrounding said first induction coil, said second induction coil having an inner diameter slightly larger than the diameter of the rod and being energizable for applying heat to the melting zone so that it is maintained in molten state, said second induction coil being displaceable in the longitudinal direction of the rod for passing the melting zone along the rod.

4. Apparatus for crucible-free zone melting a vertically mounted crystalline rod of relatively large diameter joined at one end to a seed crystal of relatively small diameter, comprising a first induction coil surrounding the seed crystal at its junction with the rod and having an inner diameter only slightly larger than the diameter of the seed crystal, said first induction coil being energizable for heating the seed crystal to a temperature at which a melting zone is formed therein and the seed crystal is fused to the rod, and a second induction coil coaxial to and surrounding said first induction coil, said second induction coil having an inner diameter slightly

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larger than the diameter of the rod and being energizable for applying heat to the melting zone so that it is maintained in molten state, said second induction coil being displaceable in the longitudinal direction of the rod for passing the melting zone along the rod, said first induction coil being relatively slightly displaceable opposite to the displacement direction of the rod away from the melting zone at the junction.

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