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CRUCIBLE-FREE ZONE-MELTING APPARATUS

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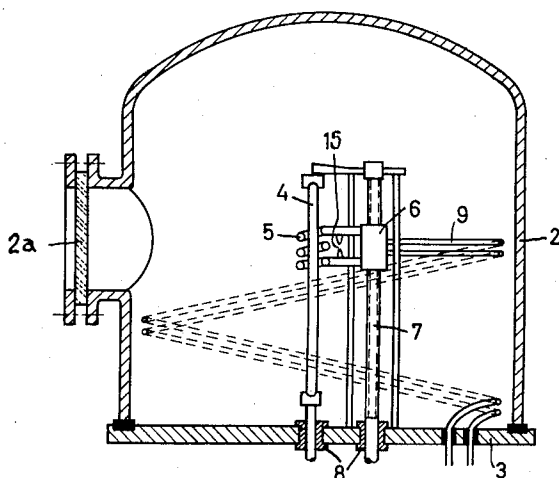


Fig. 1

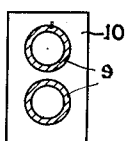


Fig. 2

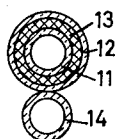


Fig. 3

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## CRUCIBLE-FREE ZONE-MELTING APPARATUS

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7 Claims. (Cl. 219—10.43)

Our invention relates to apparatus for processing crystalline substances by the so-called zone-melting method, and in a more particular aspect to zone-melting apparatus for the processing of semiconductor substances for use in electric devices with one or more p-n junctions such as rectifiers, transistors or photodiodes.

Such substances, often used in monocrystalline form and consisting of silicon, germanium, indium antimonide, indium arsenide or other semiconductor compounds, must be produced from material of extreme purity. A number of special purifying methods have been developed. Among these is the abovementioned zone-melting method according to which an axially narrow zone of rod-shaped semiconductor substance is melted and the zone is continuously shifted along the rod with the effect of causing the impurities to travel along with the molten zone toward one rod end which can subsequently be cut off. It is known to perform the zone-melting method without the aid of a crucible in order to prevent the crucible material from contaminating the semiconductor substance. According to the crucible-free method used, for example, for purifying the semiconductor substance or also for converting it from polycrystalline to monocrystalline condition, a rod of the semiconductor substance is clamped at both ends in vertical position and is then zone-melted, preferably with the aid of an induction coil supplied with medium-frequency or high-frequency current. The induction coil, whose axial length is slight in comparison with the total length of the rod material, melts only the narrow zone of the rod located within the coil, and is slowly moved longitudinally of the rod by means of a displaceable carrier or slider. The operation is preferably performed in high vacuum so that, aside from the purification due to the zone melting as such, certain impurities are liberated from the semiconductor substance by evaporation. However the processing may also be effected in a protective gas atmosphere.

Processing apparatus of this type encounter difficulties relative to the supply of alternating current to the induction coil. The two current supply leads, particularly for frequencies of 1 to 5 million cycles per second should extend as close as possible to each other and should be free of induction. These requirements should be met although only one end of the supply leads is fixed at the bottom of the processing vessel where the leads pass through a seal to an exterior high-frequency generator, whereas the other end of the supply leads is displaceable in the vertical direction together with the heater coil. Furthermore, the current supply leads must be so placed that they cannot touch other parts of the processing device proper, nor the wall of the processing vessel during the operational displacement of the coil. It is also desired that the supply leads do not interfere with the manipulations required when the processing vessel is opened and the semiconductor material is to be inserted or removed. It is fur-

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ther necessary to provide for sufficient cooling of the heating coil because otherwise the coil, whose turns closely surround the melting zone, would be excessively heated by heat-radiation. Such cooling is also desirable for preventing impurities from evaporating in vacuum out of the heater material and contaminating the semiconductor substance.

It is an object of our invention to provide a simpler and more reliable current supply to the movable heater coil of a zone-melting device than heretofore available and to more fully satisfy all above-mentioned requirements and desiderata.

According to our invention, we provide in the processing vessel of a zone-melting device a current supply assembly formed of two conductors which extend helically and parallel in slightly spaced relation to each other. Furthermore, the processing vessel has a much longer diameter than the processing device mounted therein; and the diameter of the conductor helix is only slightly smaller than the diameter of the vessel. Consequently, the parallel conductors are located close to the vessel wall and the space surrounded by the conductor helix is as wide as feasible. The two conductors are preferably made of hollow tubes and are traversed by liquid coolant for cooling the heater coil which may likewise be formed by a tubular conductor. This has the further advantage that not only the heater but also the current supply leads are subjected to cooling.

Further features and advantages of our invention will be apparent from the embodiments illustrated by way of example on the accompanying drawing in which:

Fig. 1 is a partly sectional side view of an apparatus for the crucible-free zone-melting of a semiconductor rod.

Fig. 2 illustrates a cross-section through the tubular conductors for supplying current to the heater coil in apparatus according to Fig. 1; and

Fig. 3 is a cross-section of a modified embodiment of the current supply conductors.

The vacuum vessel of the apparatus comprises a bell 2 placed upon a bottom plate 3 in vacuum-tightly sealed relation thereto. The bell 2 may consist of steel and is provided with an observation window 2a of glass. Located in approximately the center portion of the vessel space is the zone-melting device for processing the semiconductor rod 4. The device comprises a heater coil 5 fastened to a slider 6 which can be run up and down on a screw spindle 7 with which the slider is in threaded engagement. The spindle has a shaft portion passing through a sealing sleeve 8 to the outside where a suitable drive (not shown) for revolving the spindle is located. The heater coil 5 is fastened to the slider 6, for example by clamping, but is electrically insulated therefrom. The device has movable current supply conductors 9 which are soldered or brazed to the ends of the heater coil. The conductors 9 extend on a wide, helical line from the bottom plate 3 of the vacuum vessel to the displaceable slider 6, and consist of silver-plated copper tubes.

The lower ends of the conductors pass through respective openings of the bottom plate 3 and are vacuum-tightly sealed against the bottom plate. The exterior ends of the conductors 9 can be connected by means of metal strips with the terminals or secondary circuit of a high-frequency generator (not illustrated). The metal strips may be clamped fast to the respective ends of the two conductors 9 or they may also be soldered thereto. The connections for passing cooling liquid through the tubular conductors 9 and the turns of coil 5 are likewise located outside the vacuum vessel.

The tubular conductors 9 are fastened to each other

and kept at the proper spacing from each other by means of spacer pieces 10 as shown in Fig. 2. Any suitable number of such spacer pieces may be distributed along the helical conductors. The spacer pieces may consist of synthetic plastic, such as the material available under the trade name "Plexiglas." Each spacer piece 10 has two bores through which the two tubular conductors 9 are shoved as is apparent from Fig. 2.

If during operation of the apparatus the vacuum within the vessel deteriorates, there is the possibility of arcing to occur between the two conductors 9. Any arc then formed may travel along the helical conductors and may carbonize the insulating materials, for example, the spacer pieces 10. This may produce conducting paths upon the insulating bodies which may subsequently interfere with the proper operation of the device. To reliably prevent such trouble, it is preferable to provide at a predetermined location of the conductor helix an electrically weak spot or gap at which any arc will ignite and at which the arc will thereafter remain without causing damage. Such a weak spot, shown at 15 in Fig. 1, may be formed by protuberances of the respective two conductors 9 so that the conductors approach each other more closely at that spot than at any other location. The spot is preferably located near the heater coil 5 so that the arc cannot travel downwardly toward the bottom of the vacuum vessel.

For best performance, the diameter of the conductor helix should be made at least as large as the axial travel distance of the heater coil. Accordingly, the diameter of the bell 2 is much larger than, namely more than twice or three times as large as, the horizontal width of the rod-and-spindle assembly, and the perimeter of the conductor helix is closer to the walls of the bell than to the coil 5 and its carrier 6.

In the modified design of the current supply conductors shown in Fig. 3, one conductor 11 consists of a hollow copper tube and is coaxially enclosed within the other conductor 12 consisting preferably of copper braiding. Both conductors are spaced from each other by an intermediate insulation such as a layer of a double-wound tape of polytetrafluorethylene as available in commerce under the trademark "Teflon." This design of the movable current supply conductors has the advantage of reduced power losses. The cooling liquid flowing through the conductor 11 is returned through a pipe 14 which is preferably given the same dimension as the conductor 11 and which may also consist of copper. In the latter case, the tube 14 also contributes to the supply of current and thus relieves the conductor 12 of part of its current carrying duty. The tube 14, therefore, is preferably connected with the tube 12 by soldering either along the entire length of the helix or at a number of points closely spaced along the helix.

We claim:

1. A crucible-free zone-melting apparatus for processing rod-shaped material, comprising an evacuable processing vessel, holder means in said vessel for holding the rod material to be processed, said holder means defining a longitudinal rod axis, a heater member of short axial length movable along said axis for zone-melting the rod material, two conductors each having one end stationarily mounted and having the other end connected with said heater member for supplying electric current thereto, said two conductors extending between said two ends along a helical path in parallel and slightly spaced relation to each other, said helical path surrounding said holder means and said heater member.

2. A crucible-free zone-melting apparatus for processing rod-shaped material, comprising an evacuable processing vessel, having a horizontal bottom structure, two holders mounted on said structure within said vessel in

vertically spaced and axially aligned relation to each other for vertically accommodating between them the rod material to be processed, a heater coil of short axial length compared with the axial spacing of said two holders and surrounding the common vertical axis of said holders, a carrier on which said coil is mounted, said carrier being displaceable along said axis for zone melting the rod material, the horizontal width of said vessel being a multiple of the width jointly occupied by said coil and said carrier, two conductors each having one end secured to said bottom structure and having the other end connected to said coil for supplying electric current thereto, said two conductors extending between said two ends along a helical path in parallel and slightly spaced relation to each other, said helical path surrounding said holder means and said heater member and being closer to the inner perimeter of said vessel than to said coil and said carrier.

3. A crucible-free zone-melting apparatus for processing rod-shaped material, comprising an evacuable processing vessel having a horizontal bottom structure, two holders mounted on said structure within said vessel in vertically spaced and axially aligned relation to each other for vertically accommodating between them the rod material to be processed, a heater coil of short axial length compared with the axial spacing of said two holders and surrounding the common vertical axis of said holders, said coil consisting of a tubular conductor, a carrier on which said coil is mounted, said carrier being displaceable along said axis for zone-melting the rod material, the horizontal width of said vessel being a multiple of the width jointly occupied by said coil and said carrier, two tubular conductors each extending through said bottom structure into said vessel and each being connected and in communication with the tubular conductor of said coil for supplying it with electric current and with coolant, said two conductors extending along a helical path in mutually spaced and parallel relation to each other, said helical path surrounding said coil and said carrier and being closer to the inner perimeter of said vessel than to said coil and said carrier.

4. In zone-melting apparatus according to claim 3, said two helical conductors consisting of silver-plated copper tubing.

5. A crucible-free zone-melting apparatus for processing rod-shaped material, comprising an evacuable processing vessel, holder means in said vessel for holding the rod material to be processed, said holder means defining a longitudinal rod axis, a heater member of short axial length movable along said axis for zone-melting the rod material, two mutually insulated tubular conductors extending coaxially one within the other and each having one end stationarily mounted and the other end connected with said heater member to supply electric current thereto, said two conductors extending between said two ends along a helical path in parallel and spaced relation to each other, said helical path surrounding said holder means and said heater member.

6. In zone-melting apparatus according to claim 5, the inner one of said two tubular conductors consisting of copper tubing and the outer conductor consisting of copper braiding.

7. In zone-melting apparatus according to claim 1, said two conductors joining together a local gap narrower than the spacing between said conductors at all other locations along said helical path, said gap being near said heater member, whereby any occurring arcing is localized at said gap.

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