June 15, 1965 R. EMEIS 3,189,415

DEVICE FOR CRUCIBLE-FREE ZONE MELTING

Filed July 28, 1959 3 Sheets-Sheet 1

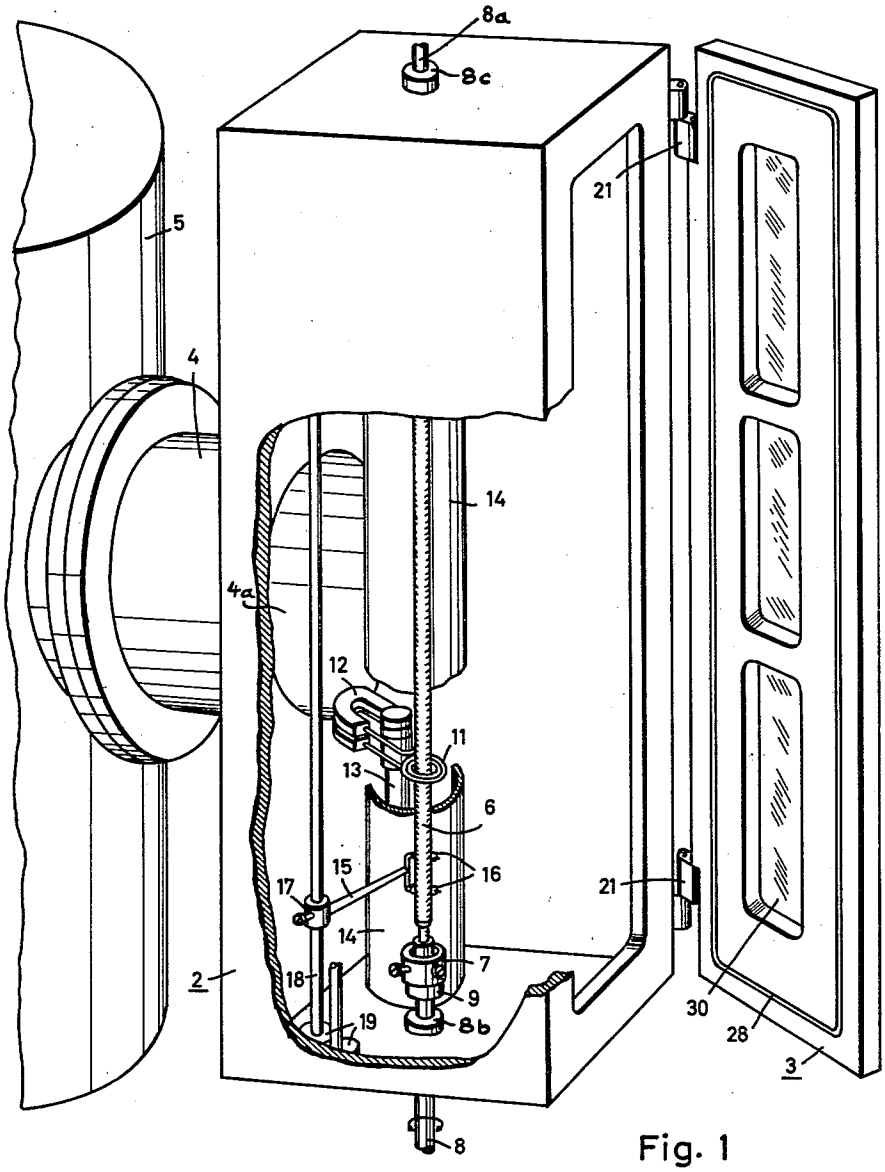

Fig. 1

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DEVICE FOR CRUCIBLE-FREE ZONE MELTING

Filed July 28, 1959 3 Sheets-Sheet 2

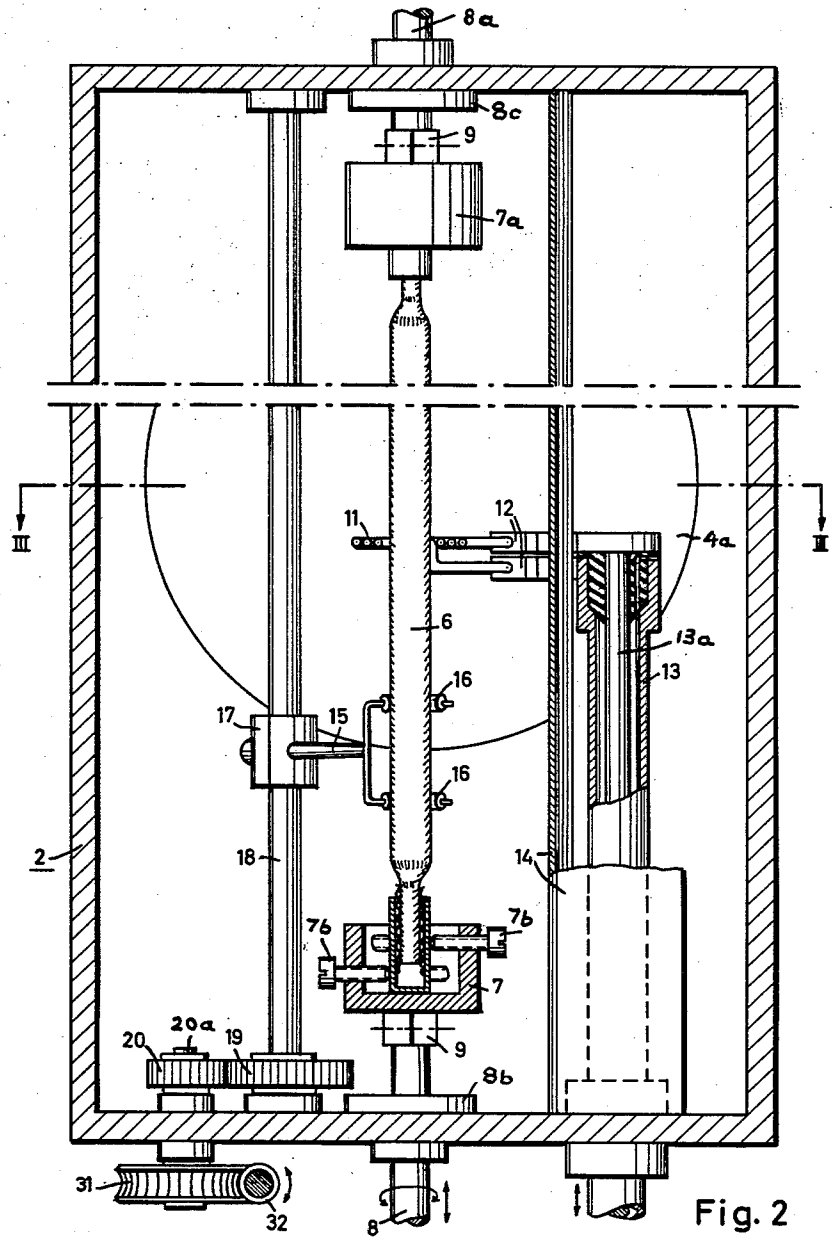

Fig. 2

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DEVICE FOR CRUCIBLE-FREE ZONE MELTING

Filed July 28, 1959 3 Sheets-Sheet 3

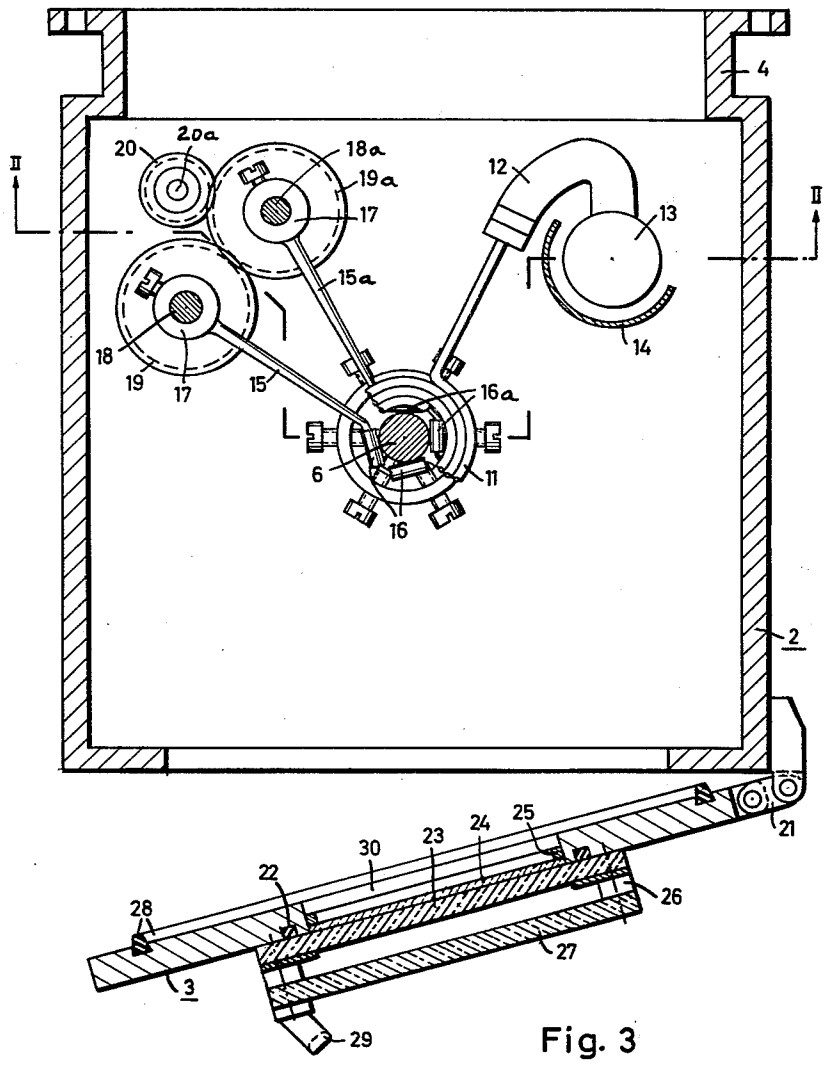

Fig. 3

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DEVICE FOR CRUCIBLE-FREE ZONE MELTING

Reimer Emeis, Ebermannstadt, Upper Franconia, Germany, assignor to Siemens-Schuckertwerke Aktiengesellschaft, Erlangen, Germany, a corporation of Germany

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4 Claims. (Cl. 23—273)

My invention relates to a device for crucible-free zone-melting of semiconductor rods, particularly silicon rods, within a metallic high-vacuum vessel in which the semiconductor rod is held vertically at both ends while being subjected to zone-melting with the aid of a ring-shaped heater surounding the rod and traveling longitudinally along the rod.

In a known device for crucible-free zone melting in high vacuum, the semiconductor rod and the zone heating device are accommodated inside a metal bell of relatively large horizontal inner width which is vacuum-tightly seated upon a base plate. The supports and other devices for holding the rod and the heater are mounted on the base plate, and all bushings and shaft seals required for driving the rod-holding devices and for shifting the zone heater along the rod are located on or in the base plate. The exhaust duct for connecting a vacuum source to the processing chamber is likewise mounted on the base plate. This involves the difficulty that foreign particles or material vaporized from the rod may drop into the exhaust duct and may reach the vacuum pump. Another difficulty is the fact that the above-mentioned parts, all mounted on the base plate, impose a severe limitation upon the diametrical size of the duct opening so that a relatively long period of time is needed, when starting the operation, for producing the high vacuum. Furthermore, for exchanging a semiconductor rod or servicing the auxiliary devices within the chamber, the bell must be lifted off the base plate by a hoisting device.

It is an object of my invention to eliminate the above-mentioned shortcomings and limitation of crucible-free zone melting devices and to provide a processing apparatus which can more readily be serviced, affords better protection of the vacuum producing equipment, and greatly reduces the starting-up time required for reducing the pressure in the processing chamber to the required high vacuum.

According to my invention, a vacuum device for crucible-free zone melting of semiconductor rods is provided with a metal housing whose interior forms the high-vacuum chamber and which is vertically elongated and has its bottom and top irremovably joined or integral with the vertical side walls. Furthermore, one of the two clamps or other holders for attaching the ends of the semiconductor rod is mounted on the bottom, and the other is mounted on the top of the housing so that the housing itself forms the supporting structure for the top holder. The vacuum chamber in the housing is accessible for servicing through a lateral, sealable opening, and another lateral opening in one of the side walls is provided for connection of the device to the high-vacuum pumping equipment, the latter opening being located in vertically spaced relation from the bottom surface of the housing.

According to another, preferred feature of my invention, the vacuum housing is given prismatic shape and a preferably rectangular horizontal cross section, and one of the vertical side walls is provided with a sealable closure device in form of a hinged door. Another one of the side walls is provided with the exhaust opening and duct for connection to the vacuum pump. Another connection for a pre-vacuum pump, if desired, may be provided on the remaining vertical side wall of the housing.

By virtue of the above-mentioned features, the diameter of the exhaust opening for producing the high vacuum within the processing chamber is not limited by the presence of the other components, nor is the interior obstructed by any supports for the upper rod holder, and the entire interior of the device is more readily accessible for servicing than is the case in the above-mentioned devices heretofore available.

The foregoing and more specific objects, advantages and features of my invention will be apparent from, and will be described in, the following with reference to the embodiment of a processing device according to the invention illustrated by way of example on the accompanying drawings in which:

FIG. 1 is a part sectional and perspective view of the device connected with evacuating equipment.

FIG. 2 illustrates the same device in a vertical section taken along the line II—II in FIG. 3, the view being from the door side of the device.

FIG. 3 is a sectional top view of the device, the section being taken along the line III—III indicated in FIG. 2.

The housing **2** of the illustrated device has generally the shape of a vertically elongated prism of rectangular or approximately square cross section. The front wall of the housing is formed by a closure plate **3** which forms a door. The walls of the housing as well as the door are preferably provided with cooling means consisting, for example, of copper tubing (not illustrated) soldered to the walls and door in order to pass a flow of cooling water through the tubing during operation of the device. An inspection window **30** extends approximately over the entire length of the semiconductor rod to be processed and permits observing the zone-melting operation. A duct **4** for connection to a vacuum pumping device **5** is mounted on the rear wall of the housing and communicates with the interior of the housing through an opening *4a* of large diameter extending over the predominant portion of the horizontal housing width. The opening *4a* and the exhaust duct **4** are located above the bottom surface of the vacuum chamber so that any particles or substances dropping onto the bottom of the device cannot enter into the vacuum equipment.

The semiconductor rod **6**, for example of silicon, is mounted in the processing chamber by means of two holders **7** and *7a*. The two holders, shown to consist of respective chucks with clamping screws *7b*, are mounted in vertical coaxial alignment on respective coaxial shafts **8** and *8a* which pass through respective vacuum-tight sealing bushings *8b* and *8c* of the housing bottom and top to the outside where they are connected with driving and control devices (not shown) which permit displacing the holders longitudinally and/or imparting rotation thereto.

The device is further provided with a ring-shaped zone heater consisting of a flat induction coil **11** mounted on terminal blocks **12** of a shifting device **13** which permits moving the axially narrow heater **11** vertically along the rod **6** in order to melt a correspondingly narrow zone of the rod and to displace the molten zone gradually along the rod axis. A semi-cylindrical shield **14** of sheet metal protects the device **13** from heat radiation coming from the molten zone and also from deposition of evaporated material.

The heater and the shifting device are mounted along one of the corner areas of the prismatic processing chamber. As best apparent from FIG. 2 the device **13** comprises several concentric tubes which are separated from each other by evacuated interspaces and also serve for supplying the electric current to the terminal blocks **12** of the heater coil **11**. The coil **11** consists of a copper tube which forms part of a coolant circulation system. The coolant passes from the outside of the housing through

the inner tubular portion 13*a*, thence through one of the hollow blocks 12, the tubular coil 11, the other block 12, and through the cylindrical interspace around the tube 13*a* back to the outside of the processing device.

The heat shield 14 is fastened to the top and bottom of the vacuum housing by screws and may be provided with water cooling, for example, with the aid of copper tubing (not shown) soldered to the shield 14.

A gripper device, comprising two vertical shafts 18 and 18*a*, is mounted along another edge of the prismatic processing chamber, preferably, and as shown, near one of the two edges remote from the door. As is best apparent from FIG. 3 two grippers 15 and 15*a* are fastened by means of set screws to the respective vertical shafts 18 and 18*a*, the two grippers being longitudinally displaceable so that they can be secured in any desired height. The shafts 18 and 18*a* carry respective spur gears 19 and 19*a* which are in mesh with each other and are driven by a spur gear 20 whose shaft 20*a* extends through a rotational seal to the outside where it is actuated by a worm gear 31 and worm 32 preferably of the self-locking type. For protecting the semiconductor rod 6 from being contaminated, the ends of the grippers 15, 15*a* are provided with tubular pieces 16 of heat-resistant and wear-resistant material, preferably quartz.

The gripper device facilitates servicing and affords eliminating one or more operating steps, such as opening and closing of the door, inserting a semiconductor rod and evacuating the housing, thus saving a considerable amount of time, for example in a case where the rod 6 proper is to be inserted between two rod pieces of crystal seeds previously fastened in the respective holders 7 and 7*a*, and is then to be fused together with these seed pieces. For such operation, the rod pieces or seeds can be clamped in the holders and the rod proper can be fastened in the gripper device when the door is open and the zone melting device is being set up for operation. Then the door can be enclosed and the housing evaporated, whereafter the fusing operation required for joining the rod 6 with the end pieces or seeds can be effected with the aid of heater coil 11, and the zone melting proper can be carried out without requiring renewed opening of the door or renewed evacuation of the processing chamber.

As shown in FIG. 3 the door-like closure plate 3 carries a rubber gasket 28 which is seated in a swallow-tail groove or otherwise fastened to the door. The door is joined with the housing by double-type hinges 21 whose two hinge axes are approximately located in the plane of the door when the door is closed and tightened. This affords obtaining a vacuum-tight sealing of the door under the effect of the ambient pressure without encountering lateral displacement of the door as a consequence of pressure changes. The door is provided with a handle 29.

The observation window 30 is covered by a hard-glass pane 23 of sufficient thickness to withstand all occurring pressures. The pane 23 is vacuum-tightly sealed by means of a gasket 22 preferably of rubber. An exterior protective sheet 27 of transparent and splinter-proof glass, plastic, or glass-plastic composition, is mounted on spacer tubes 26 at some distance from the hard-glass pane 23, leaving an interspace preferably about equal to the thickness of pane 23. The protective sheet 27 consists preferably of polymethylmethacrylate known under the trade name Plexiglas. For protecting the hard-glass pane 23 from being soiled by evaporated material, another thinner glass pane 24 is removably inserted on the inner side of the door. The auxiliary pane 23 is held by means of a spreading spring 25 so that it can readily be removed or exchanged for cleaning purposes. The inner pane 24 may also be attached by other means, such as by one or more leaf springs attached by screws to the door. For protecting the observer's eyesight, the sheet 27 may be given a dark coloring so that no protective goggles are needed for observing the melting operation.

The horizontal spacing of the observation window from the vertical axis of the rod holders 7, 7*a*, is preferably at least five times the inner diameter of the ring-shaped heater coil 11 in order to prevent the deposition, forming itself on the inside of the observation window due to material evaporating from the rod, from becoming so dense as to interfere with proper observation within too short a processing time. The just-mentioned spacing determines the locations at which shafts 8 and 8*a*, and the appertaining vacuum-tight seals pass through the top and bottom of the housing 2.

A tubular cooling trap may be mounted in one of the remaining front corners of the vacuum chamber. Such a trap may be mounted on the top of the housing 2 so as to suspend therefrom. The trap tube, being closed at the bottom toward the interior of the processing chamber, may have its upper, open end passing vacuum-tightly through the top of the housing so that it can be filled from the outside with coolant, for example liquid air.

It will be obvious to those skilled in the art, upon studying the disclosure, that my invention permits of various modifications with respect to design and arrangement of the device components and hence may be embodied in apparatus other than particularly stated and described herein, without departing from the essential features of my invention and within the scope of the claims annexed hereto.

I claim:

1. A device for crucible-free zone melting of silicon and other semiconductor rods, comprising a stationary metal housing of generally prismatic and vertically elongated shape forming a vacuum chamber and having rectangular vertical side walls and respective horizontal top and bottom parts irremovably joined with said walls, two semiconductor-rod holders mounted on said respective top and bottom parts in vertical and coaxial alignment on an axis substantially coincident with the vertical center axis of said housing for holding the respective ends of the rod to be processed, a ring-shaped induction heater surrounding the vertical rod-holder axis and being displaceable in the axial direction, the vertical front wall of said housing having an access opening for servicing said chamber, said access opening having a height equal to at least the major part of the maximum axial displacement of said heater, a closure member pivotally mounted on said housing in front of said front wall to close said access opening and sealing means between said housing and said closure member, said closure member having an observation window extending vertically over a major part of the height of said access opening and comprising a transparent, pressure-withstanding outer pane and a removably mounted inner pane to protect said outer pane from soilage, said housing having an evacuating opening in the vertical rear wall and having an evacuating duct communicating through said opening with said chamber, said latter opening having a width substantially equal to that of said chamber and being upwardly spaced from said bottom part, the lower one of said rod holders being vertically displaceable, two rod-shaped drive means for axially displacing said one rod holder and said heater respectively, said respective drive means extending through said housing bottom part to the outside, and said rod-shaped drive means for said heater extending vertically between said center axis and one of the vertical rear edges of said housing.

2. In a device for crucible-free zone melting of a meltable rod, a stationary housing, two holder members in the housing, means for relatively displacing the holder members vertically with respect to each other, a melting coil in the housing, means for supporting and for relatively displacing the coil vertically of the vertical axis of the holder members; the improvement therein, the housing having an access opening having a height substantially at least as great as the entire vertical displacement path of the melting coil, and a closure mem-

ber for said opening having an observation window extending over at least the major part of the height of the opening, and two rod-gripping devices in said housing, each including a rotary vertical shaft and a gripper means mounted on the shaft, and means extending through the housing to turn the shafts to position the grippers on opposite sides of the rod to hold the rod, so that upon opening the closure member the rod can be placed and held between the holders at the start of the melting operation, and, after closing the closure member and commencing the melting, the grippers can be turned away from the rod to permit the said relative displacement of the melting coil.

3. A device for crucible-free zone melting of silicon and other semiconductor rods, comprising a stationary metal housing of vertically elongated shape forming a vacuum chamber and having vertical side walls and having a top and a bottom irremovably joined with said side walls, two semiconductor-rod holders mounted on said top and said bottom respectively in vertical and coaxial alignment for holding the respective ends of the rod to be processed, the axis of said holders being substantially coincident with the vertical center axis of said housing, a ring-shaped induction heater surrounding said rod-holder axis and being displaceable along said axis a distance constituting a major portion of the height of said chamber, vertically displaceable means in said chamber for supporting and moving said heater along said distance, the vertical front wall of said housing having an access opening extending vertically from one of said holders to the other for servicing said chamber, a sealable closure plate covering said access opening during zone-melting operation and having a vertically elongated observation window extending over substantially the entire vertical displacement path of said induction heater, said cover plate being hinged to said housing and having a vertical hinge axis for opening movement of said plate in the outward direction away from said access opening, said

housing having an evacuating opening located in the vertical rear wall and having a diameter substantially equal to the width of said chamber, said housing having an evacuating duct communicating through said latter opening with said chamber, and said means for supportin said heater extending vertically in the rear portion of said chamber so as to be located behind said rod holders relative to said access opening.

4. In a zone-melting device according to claim 3, said housing having the shape of a vertically elongated prism with rectangular cross section, said closure plate having substantially the same size as said vertical front wall of said housing, and said heater supporting means extending through said bottom part to the outside of said housing and along a rear vertical edge of said chamber at a place substantially between said rear edge and said rod-holder axis.

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NORMAN YUDKOFF, *Primary Examiner.*

MAURICE A. BRINDISI, GEORGE D. MITCHELL, *Examiners.*