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[54] **APPARATUS AND METHOD FOR FLOATING-ZONE MELTING OF A SEMICONDUCTOR ROD**

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[58] **Field of Search** 219/10.57, 10.41, 219/10.75, 10.77, 10.79; 13/DIG. 1, 1; 317/242

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[57] **ABSTRACT**

This invention provides a device for the floating-zone melting of a semiconductor rod. The device comprises a treatment container having means to mount a semiconductor rod therein, a resonant circuit capacitor slidably mounted and sealed in an opening in a wall of the treatment container, said resonant circuit capacitor being a part of an electrical circuit resonantor, connecting wires extended from said resonant capacitor to a high frequency generator outside of the treatment container, and a single-wound induction heating coil movably mounted within said treatment container and arranged to be concentrically positioned around said semiconductor rod, said heating coil being connected at one end to the inner conductor of the resonant capacitor and at the other end to the outer conductor of said capacitor.

12 Claims, 2 Drawing Figures

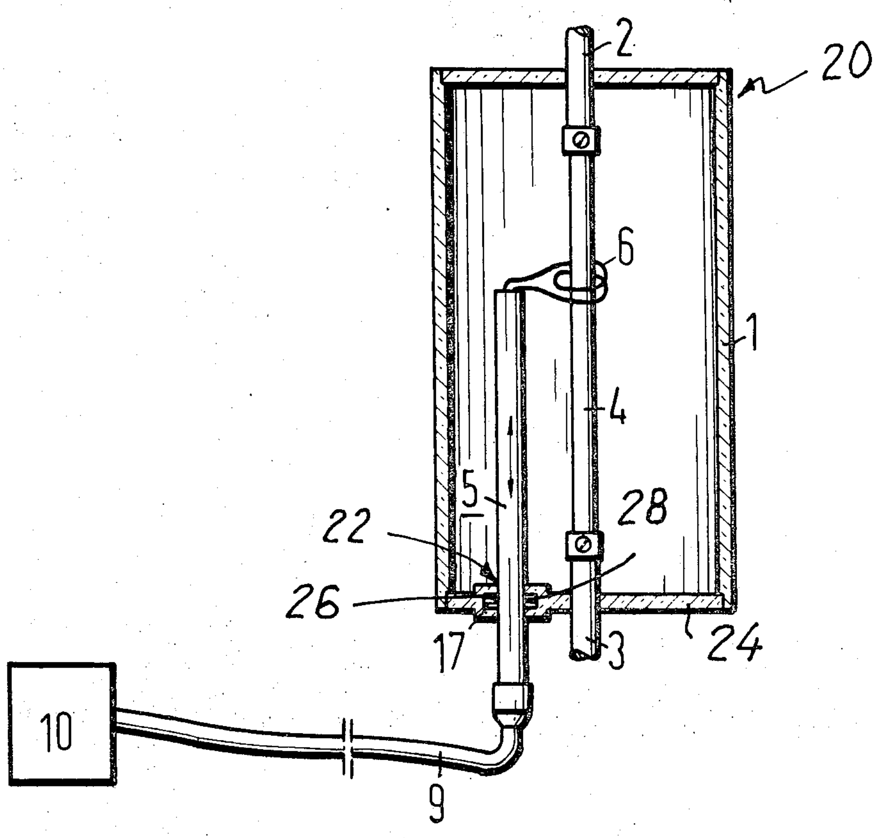

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Fig.1

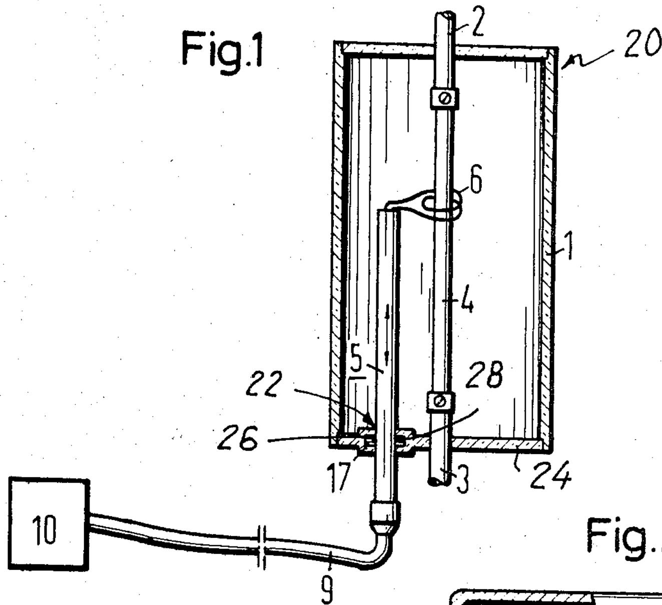
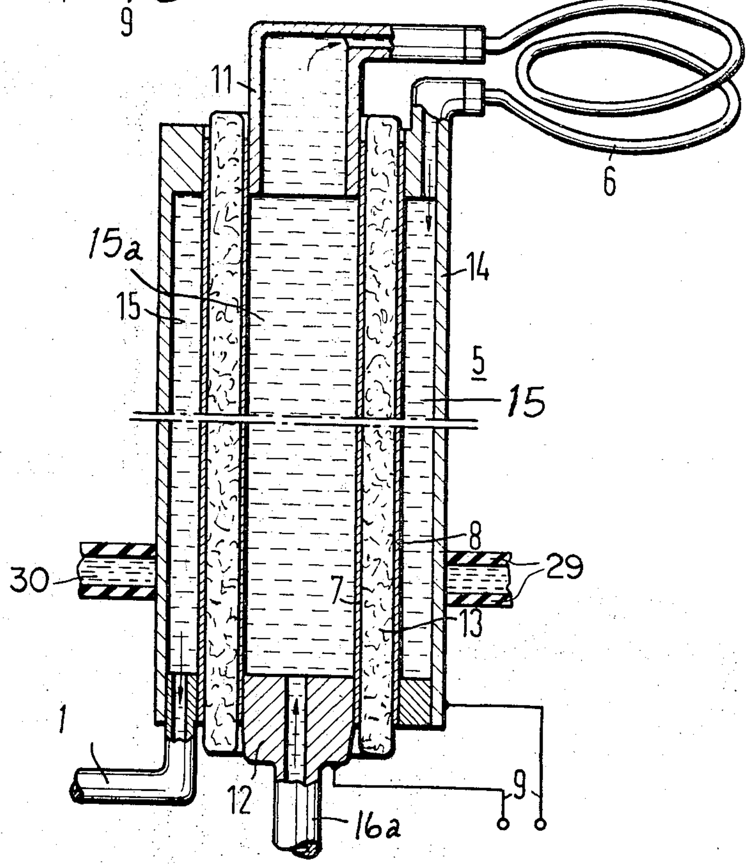


Fig.2



APPARATUS AND METHOD FOR FLOATING-ZONE MELTING OF A SEMICONDUCTOR ROD

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a method and device for the floating-zone melting of a semiconductor rod. More particularly, this invention relates to a device having a single-wound induction heating coil arranged in a treatment container to coaxially move with respect to a semiconductor rod mounted therein.

Generally, such devices that are used for the floating-zone melting of a rod such as a semiconductor rod are disclosed and described in German Pat. DAS 1,188,043 and German Pat. DOS 1,444,530. Such devices have a high frequency source which is arranged outside the treatment container in which the semiconductor rod is to be treated by zone melting and an induction heating coil which is also arranged inside the treatment container. The heating coil generally is slidable in a parallel manner to the axis of the mounted semiconductor rod within the treatment container. In such devices, the connecting cable or wire from the heating coil is generally placed through an electrical passage in the wall of the treatment container for the electric connection between the high frequency generator and the induction heating coil, whereby the induction heating oil is connected at both ends to the high frequency generator through the same electrical passage.

The conneting electrical circuit, i.e., the connecting cable and the passages as well as the induction heating coil, which is effective between the high frequency generator and the semiconductor rod, does not have an alternating current which is exclusively real. This is true because the electrical current which is induced by the effect of the electrical field of the induction heating coil in the semiconductor rod, contains a power component as well as a reactive component. However, due to the presence of the reactive component, the degree of efficiency of the heating is decreased. Thus, there is a need to reduce the reactive component as much as possible.

SUMMARY OF THE INVENTION

In view of the disadvantages of prior devices for zone melting semiconductor rods, the present invention provides an improved device for the floating-zone melting of semiconductor rods which is efficient, practical and effective.

According to the present invention, a device is provided which is designed to reduce the reactive component of the electrical current which is induced by the effect of the electrical field of the induction heating coil. For this purpose, the present device includes a capacitor arranged in parallel to the heating coil to form an electrical resonant circuit. Since the reactive components of the current are primarily due to the induction coating of the supply lines between the high frequency generator and the induction heating coil, a reduction of the reactive impedance of the circuit as well as a reduction of the reactive component of the heating current which is induced in the treated rod is obtained by the parallel arrangement of the capacitor in the device. The parallel capacitor is purposely arranged in proximity of the induction heating coil so that it is pro-

tected against the radiation of the hot melting zones which are necessary in melting the semiconductor rod. Also, the capacitance of the capacitor should be sufficiently high in order to compensate and overcome the reactive component of the electric current induced by the induction heating coil.

According to the present invention it is advantageous to have the supply line or connecting wires from the high frequency generator to the capacitor as well as the capacitor itself self-inductive in order to exert a certain influence on the characteristics of the electrical resonant circuit and to increase the entire inductance of the electrical resonant circuit.

The present device for the floating-zone melting of a semiconductor rod, comprises a treatment container having means to mount therein a semi-conductor rod, a resonant circuit capacitor slidably mounted and sealed in an opening in a wall of the treatment container and forming a part of an electrical resonant circuit, connecting wires extending from the capacitor to a high frequency generator outside of said treatment container, and a single-wound induction heating coil movably mounted within said treatment container, said heating being arranged to be concentrically positioned around said rod within said treatment container and connected at one end to the inner con-ductor of the resonant capacitor and at the other end to the outer conductor of the capacitor.

It therefore, is an object of the present invention to provide an improved device for the floating-zone melting of a semiconductor rod.

A more specific object of the present invention is to provide a device for the floating-zone melting of a semiconductor in which the reactive component of the electric current induced by the heating coil in the semiconductor rod, is reduced to a minimum.

Other objects, features and advantages of the invention will be readily apparent from the following description of certain preferred embodiments thereof, taken in conjunction with the accompanying drawings, although variations and modifications may be effected without departing from the spirit and scope of the novel concepts of the disclosure.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a schematic view of a device embodying the present invention; and

FIG. **2** is an enlarged sectional view of the resonant circuit capacitor and induction heating coil of the device shown in FIG. **1.**

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1,** there is schematically shown a device embodying the present invention. The device, generally referred to by the numeral **20,** is primarily useful for the floating-zone melting of a rod such as a semiconductor rod **4.** The device, as shown, includes a cylindrical treatment container **1** which has mounting means **2** and **3** for movably and rigidly mounting as desired, the semiconductor rod **4** within the treatment container. The mountings **2** and **3** may be arranged to be axially shiftable with respect to each other. Mounted within an opening **22** in the bottom wall or end cover **24** of the treatment container **1** is a resonant circuit capacitor **5** which is slidably mounted but sealed within the opening **22.** As shown in FIG. **2,** the resonant capacitor **5** is a rigid coaxial line which can be moved vertically upward and downward in a parallel manner with respect to the semiconductor rod **5** within the treatment container **1.** The resonant capacitor **5** is supported in the opening **22** at the passage point **17** through the bottom cover **24** of the treatment container **1** by respectively sealed passages **26** and **28** in such a way that the axial shifting of the resonant circuit capacitor **5** or vertical movement of the resonant circuit capacitor **5** at the passage point **17** is possible without any outer air being admitted into the treatment container **1.** Thus, there is provided in effect, a vacuum within the treatment container.

As illustrated in FIGS. **1** and **2,** a single-wound induction heating coil **6** is connected to the resonant circuit capacitor **5** within the treatment container **1.** The induction heating coil **6** is arranged to be coaxially positioned around the semiconductor rod **4** and to be axially shifted with rerespect to the rod **4** which is to be treated.

The resonant circuit capacitor **5** may be merely a mounting or holder for the heating induction coil **6,** although it is preferred to have the holding or mounting means for the heating coil **6** as a resonant circuit capacitor to provide an electrical resonant circuit as described hereinbelow. In such case, as shown in FIG. **2,** the resonant capacitor **5** may only consist of an inner conductor **7,** a tube-saped massive capacitor dielectric **13** and an outer conductor **8.** Both the inner **7** and outer **8** conductors can be connected directly at their upper ends with the respective ends of the single-wound induction heating coil **6.**

As shown in FIG. **1,** the resonant capacitor **5** is connected by means of a connecting line or coaxial cable **9** to a high frequency generator **10** located outside of the treatment container **1.** The connecting line **9** is preferably arranged as a coaxial cable. The connecting line **9,** however, is flexible whereas the resonant circuit capacitor **5** is rigid and solid. The connecting line **9** can be made of a common dielectric plastic material such as polyethylene or polytetrafluoroethylene. The relative capacitance per meter of the coaxial cable **9** made of such material is between about 30 and 100 picofarads.

During the floating-zone melting of the semiconductor rod **4** which is preferably made of silicon, the frequency of the alternating current which is supplied by the high frequency generator **10** is adjusted to approximately 3 to 4 Mega-Hertz to provide the optimum heating effect. Because of the inductance of the heating coil which is provided in the case of the common high frequency connecting line **9,** a resonant circuit capacitance of at least 20 nano-farads, and preferably between 30 and 40 nano-farads, would be needed to effectively reduce the reactive components of the electrical current induced by the heating induction coil **6** in the semiconductor rod which is to be zone melted. This capacitance is obtained without the simultaneous increase of inductance of the heating coil.

It is noted that if a conventional coaxial cable would be used as a resonant circuit capacitor, great lengths of this coaxial cable would be needed to perform the function of the resonant circuit capacitor illustrated in the drawings. Accordingly, this would provide a considerable increase of the inductance of the entire electrical resonant circuit and also increase the undesired reactive components of the electrical current induced by the heating coil in the semiconductor rod.

However, according to the present invention, by using a massive capacitor dielectric **13** with a relative dielectric constant of at least 10, and in some cases a dielectric constant of at least 100, the desired melting would be achieved so that the capacitance of such a coaxial cable would increase by the same factor whereby the relative inductance of the heating coil would not be affected or increased. Accordingly, it is preferred to use ceramics as the resonant capacitor dielectric such as a titanic oxide or magnesium titanic which are especially well suited as the capacitor dielectric. Thus, the required resonant circuit capacitance with an inductively low coaxial capacitor **5** can be easily obtained, whereby the length of the coaxial capacitor **5** is no larger than that of the minimum length of the semiconductor rod **4** which is required for zone melting.

The coaxial capacitor **5** as illustrated in FIG. **2,** can be constructed by having an outer coaxial metal tube **14.** This tube then will provide the metal protection of the capacitor since it can be slid in the same direction as the inner conductor **7** whereas the capacitor **5** itself can be rigidly arranged in this tube **14.** A further development of this type of capacitor can be provided as disclosed in the German specification DOS 1,916,316. In this specification there is described a device for inductive floating-zone melting of rods with an induction heating coil which is arranged in a closed off treatment container for creating and heating the melting zone in the rods to be treated. Th induction heating coil is connected by means of an electrical supply line with an energy source that is arranged outside the treatment container. In this construction, the part of the electrical supply line which is passed through the wall of the treatment container consists of several tube-shaped single conductors which are arranged in a coaxial way to each other. The tube-shaped single conductors are divided into two groups in such a manner that each group consists of single conductors which are connected in parallel to each other and each single conductor includes only a single conductor of the other group. Preferably, the outer tube of these tube-shaped conductors forms with its adjacent conductor the resonant circuit capacitor which is fixed within the other tube-shaped capacitor coaxially by suitable means; for example, by means of a massive dielectric having a high dielectric constant. By such a parallel connection of the conductors of the resonant capacitor, the inductance as well as the capacitance of the entire electrical resonant circuit is increased. Thus, by this construction there is provided according to the present invention another embodiment of a device which reduces the reactive components of the electrical current induced by the heating coil in the semiconductor rod.

In the preferred embodiment according to the present invention, the mounting **5** for the induction heating coil **6** is the resonant circuit capacitor that is concentrically positioned in the interior of the cylindrical metal tube **14.** As shown in FIG. **2,** the resonant circuit capacitor **5** is thus formed with a ceramic tube **13** having a large dielectric constant, and with a metal layer as the inner conductor **7** on the inner wall of the tube **13** and an insulating metal layer as the outer conductor **8** on the outer wall of the ceramic tube **13.** The metal tube **14** which surrounds the capacitor is designed as a container for water cooling means **14** and **15***a*. For this purpose the tube **14** is closed off at its upper and lower ends with the exception of the entries and exits for the cooling means **15** and **15***a*. As shown in FIG. **2**, this capacitor is permeated by the body of the actual resonant circuit capacitor in its entire length in such a way that the interior of the container consists of two eccentric chambers which are separated from each other by the capacitor. One of these chambers is located in the interior of the tube shaped capacitor member whereas the other chamber is enclosed on the outside by the tube **14** and on the inside by the tube shaped capacitor member. Both chambers are provided with two connection pipes **16** and **16***a* for the respective cooling means **15** and **15***a*. The cooling means reaches the inner chambers for instance by means of the lower termination or sealing ends **12** of the resonant capacitor **5** for the induction heating coil **6** from where it goes by means of the upper terminal **11** carrying the induction coil **6** by means of the outer chamber of the resonant capacitor **5**.

The capacitor **5** is constructed so that the ceramic tube **13** insulates electrically the two parts of the metallic terminals **11** and **12** as well as the inner **7** and outer **8** conductors, in respect to each other. The contacting of the conductors **7** and **8** of the capacitors is provided by means of the coaxial cable **9**, as indicated above, whereby the cable **9** contacts electrically by means of the outer part of the lower terminal **12**, the outer conductor **8**, and by means of the inner part of the terminal **12**, the inner conductor **7** of the resonant capacitor.

The inner conductor **7** constitutes the electric connection to the inner part of the terminal **11** which together form one electrical connection with the induction coil **6**, while the other electrical connection of the induction coil **6** is formed by the outer conductor **8** and possibly the metallic outer conductor tube **14** as well as the outer part of the terminal **11**.

The inner and outer components of the terminals **11** and **12** may be connected with the capacitor member as well as with the metal tube **14**, the induction coil **6** and the ends of the connecting cable **9** by self-soldering. In addition, the terminals, particularly terminal **11**, may be sealed with a protective layer (not shown) consisting of heat resistor material such as silicon or polytetrafluoroethylene.

The treatment container **1** is preferably made of a stable material such as quartz. The inner conductor **7** and the outer conductor **8** of the capacitor may for instance consist of silver which is burned onto the surface of the ceramic tube **13**.

The passage or contact point **17** of the resonant capacitor **5** in the opening **22** of the bottom cover **24** of the treatment container **1**, may be a gasket which can consist, for example, of several ring-shaped gaskets **29** (two shown) which are arranged in a stack and are tightly connected at the passage point with the cover **24** of the treatment container **1**. The spaces between the adjacent gaskets can be filled with a suitable liquid sealing means **30** which should be temperature resistant and as little as possible, volatile.

It is noted that it is also possible to accommodate two or several parallel-connected resonant capacitors **5** within the outer tube **14**. In this case, a concentric or eccentric arrangement of both capacitors is possible. However, it has been found that the capacity which can be achieved by a coaxial capacitor of 20 to 30 centimeters in length is sufficient to effectively reduce the reactive components of the electrical current induced by the heating coil **6** in the semiconductor rod **4**, and to substantially increase the effective heating and melting thereof.

It is clear from the above description of the present invention that an improved device is provided for the effective floating-zone melting of a semiconductor rod in that it is constructed to substantially reduce the reactive component of the electric current induced by the heating coil **6** in the semiconductor rod.

Although minor modifications might be suggested by those versed in the art, it should be understood that we wish to embody within the scope of the patent awarded hereon all such modifications as might reasonably and properly come within the scope of our contribution as defined by the appended claims.

We claim as our invention:

1. A device for the floating-zone melting of a semiconductor rod which comprises:

a treatment container having means for mounting therein

a semiconductor rod;

a resonant circuit coaxial capacitor having an inner conductor means and an outer conductor means and slidably mounted and sealed in an opening in a wall of the treatment container;

a high frequency cable including connecting wires extended from said capacitor to a high frequency generator positioned outside of the treatment container, said wires connected to respective ones of said conductor means; and

a wound induction heating coil movably mounted in said treatment container, said heating coil being arranged to be concentrically positioned around said semiconductor rod and connected at one end to the inner conductor means of the resonant capacitor and at the other end to the outer conductor means of said capacitor.

2. A device according to claim **1**, wherein the resonant capacitor has a capacitance of at least 20 times as large as the capacitance of the connecting wires extended from the capacitor to the high frequency generator.

3. A device according to claim **2**, wherein the induction heating coil is mounted only on the resonant circuit capacitor.

4. A device according to claim **1**, wherein said inductive heating coil and resonant circuit capacitor are axially shiftable with respect to said semiconductor rod in the treatment container.

5. A device according to claim **1**, wherein the resonant circuit capacitor is concentric with at least one other concentrically arranged metal tube.

6. A device according to claim **1**, wherein the dielectric constant of the massive dielectric of the resonant circuit capacitor is at least 10 times larger than the dielectric constant of the insulation of the connecting wires to the high frequency generator.

7. A device according to claim **1**, comprising a gasket in the wall of said treatment container, said outer conductor means of the resonant circuit capacitor passing through said gasket, said gasket consisting of several ring-shaped gaskets which are tightly and sealably connected with the wall of the treatment container whereby the spaces between said ring-shaped gaskets are filled with an inert liquid sealant.

8. A device according to claim 7, wherein the dielectric of the resonant circuit capacitor consists of a ceramic having a high dielectric constant.

9. A device according to claim 8, wherein the dielectric is composed of material selected from the group consisting of titanium dioxide and magnesium titanic.

10. A device according to claim 8, wherein the resonant circuit capacitor comprises a tube of insulating material having an inner conductor at its inner surface and an outer conductor at its outer surface, said inner and outer conductors being arranged in the form of two metal layers which are insulated with respect to each other.

11. A device according to claim 10, herein the resonant circuit capacitor is enclosed in a metal tube which is closed off at both ends by terminals in a manner so that the inner space between the metal tube and capacitor is divided into two separate chambers which are in communication with each other by means of said induction heating coil.

12. A device according to claim 11, wherein said chambers are arranged with one having an entry and the other an exit for the passage of a cooling means through said resonant circuit capacitor.

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