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APPARATUS FOR PRODUCING CRYSTALLINE SEMICONDUCTOR MATERIAL

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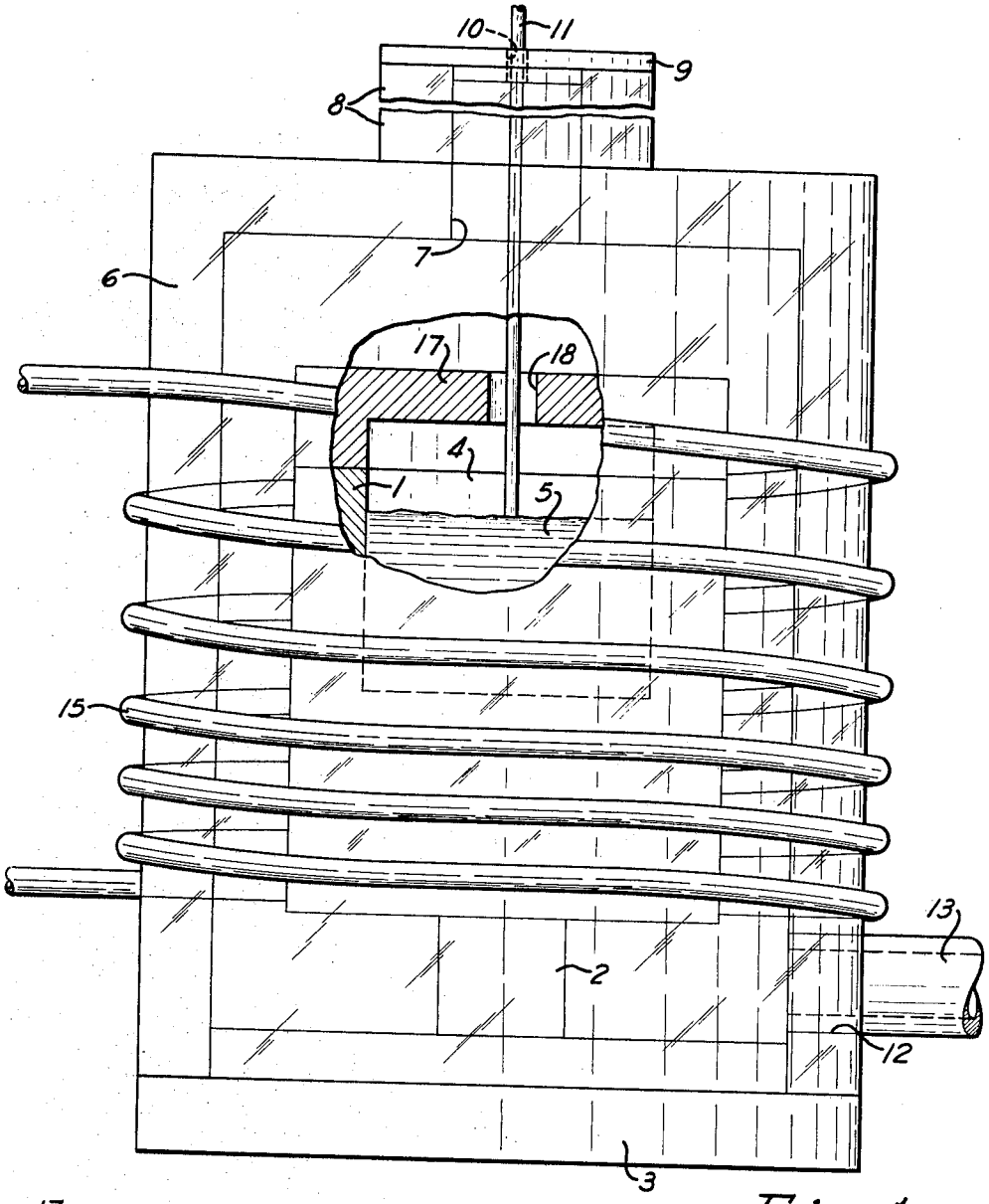


Fig. 1

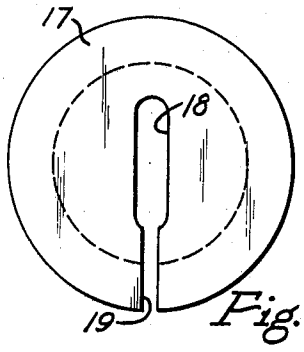


Fig. 2

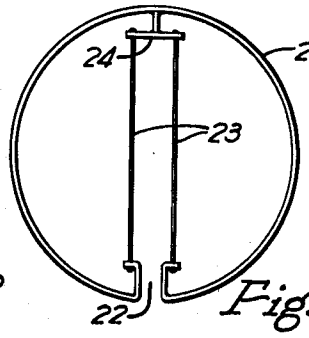


Fig. 3

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APPARATUS FOR PRODUCING CRYSTALLINE SEMICONDUCTOR MATERIAL

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This invention relates to apparatus for growing ribbons and other shapes of crystalline semiconductor material from a melt in a heated crucible.

Conventional apparatus is available for producing a solid crystal from a molten pool of suitable material. Such apparatus includes means for contacting the surface of the melt with a previously prepared crystal or seed and then slowly withdrawing the seed. The seed pulls after itself a portion of the melt which solidifies on the seed, so a crystal of indefinite length can be produced. In growing crystals the thermal gradient at the surface of the melt is important. Unless it is controlled properly the result can be the growth of thick, rough crystals or even no growth at all. If the top of the crucible is open, the melt surface radiates heat at a rate depending on its emissivity and temperature, and the thermal gradient at the melt surface and just within the melt will be equal to the radiation loss per unit area divided by the thermal conductivity of the melt. In many cases, such as in the growth of silicon dendrites, this thermal gradient is unsuitably high. One way of reducing it has been to place a radiation shield over the melt to reflect some heat back to the melt surface and thereby reduce the total heat loss. However, the reduction in gradient is limited when such a passive radiation shield is used, because it at best returns to the melt surface only a fraction less than unity of the heat originally radiated by that surface.

It is among the objects of this invention to provide apparatus including a thermal gradient control member, for producing high-quality crystalline semiconductor material that does not deteriorate materially and that can be formed in indefinite lengths. A further object is to provide such apparatus, in which supercooling of the melt is controlled to any desired extent.

The invention is illustrated in the accompanying drawings, in which—

FIG. 1 is a side view of apparatus constructed for my purposes;

FIG. 2 is a reduced plan view of the thermal gradient or supercooling control member on the crucible; and

FIG. 3 is a plan view of a modification.

In accordance with this invention, thermal gradient control is achieved, in conjunction with a crucible or like member, with a member to be used therewith having a particular configuration and heated in a particular manner. Consequently the application of heat is localized in an advantageous manner permitting fine control of the thermal gradient in the unit defined thereby.

For ease of understanding, the invention will be described with particular reference to its use in control of supercooling. It should be understood, however, that the invention is not to be limited to the details given.

Referring to FIG. 1 of the drawings, a crucible **1** of well-known construction for growing dendrites and other crystalline semiconductor materials is made from graphite or the like and may be mounted on a center post **2** projecting up from a base member **3**. The upper part of the crucible is provided with an upwardly opening recess **4** to contain the material **5** from which a crystal is to be formed. The crucible is mounted in a furnace of any suitable construction, the one shown being a cylindrical furnace **6** formed from quartz or the like to provide ample visibility into its interior. The top of the furnace is provided with a small central opening **7**, from which a tube **8** extends upwardly. The upper end of the tube is closed by a cover **9** that has a central opening **10** just large enough to receive a rod **11** or other suitable elongated member, by which a crystal can be drawn from the crucible. The side wall of the furnace is provided with an opening **12** connected to a pipe **13**, through which an inert gas can be delivered to the inside of the furnace or the air exhausted from the furnace.

The crucible is heated by a radio-frequency (RF) coil **15** encircling it. This coil may be either inside or outside of the furnace, outside being preferred. The turns of the coil may be closer together at the bottom of the crucible than at its top so that there will be a thermal gradient present in the crucible-melt system to insure that the surface of the melt and the melt just below its surface will be the coolest points of the melt. Also, this thermal gradient maintains the bottom part of the melt, which is in contact with the crucible, at a temperature higher than the melting point of the melt, whereby the melt is prevented from freezing at the bottom.

A feature of this invention is that the desired thermal conditions for continued crystal growth are maintained by producing heat above the melt and radiating it downwardly against the central area of the upper surface of the melt, whereby to reduce the thermal gradient in the melt and thereby control supercooling of the top of the melt. This is accomplished by a supercooling control member **17** of special form that is made of electrical conducting material. It is placed on top of the crucible and has a center opening **18** in its top for accommodating rod **11** and to permit the growing crystal to be removed from the crucible. The control member is heated by radio-frequency induction, which may be provided directly from the same coil that heats the crucible, or by a separate coil or other means provided with its own current supply, or by use of a coil turn separate from the coil that heats the crucible but which influences or controls (short circuits) the field from that coil insofar as the control member is concerned. Where the control member is other than in accordance with my discoveries, the induced currents will tend to flow only around the periphery of the control member and to generate heat only there. In dendritic growth especially, the control member should radiate heat to the central region of the melt surface in particular, where the dendrite is growing. Thus, when the supercooling control member is in the form of a graphite cover and a radio-frequency of 450 kc. is used for heating it, the heat will be induced in the cover almost entirely to a depth of not more than 2 mm. from the periphery of the side wall of the cover. Furthermore, the crucible and its molten charge will effectively shield the cover from any magnetic fields that otherwise might induce heating near the center.

The above skin effect problem is solved by shaping the supercooling control member so that most of the heat will be radiated from it at or near the top wall about the central opening **18**. This is accomplished by making that opening **18** in the form of a slot that is completely open at one end. In other words, there is a gap **19** in the side wall of the cover, and this gap opens into the adjoining end of the slot to form a re-entrant opening. With this construction, the induced currents no longer can flow completely around the cover because the gap in its side wall interrupts the current path. Therefore, these currents, to complete their circuit flow along the walls of the gap and around the side wall of the slot, which causes the central area of the control member to be heated so that it can radiate the induced heat to the central area of the melt. In effect, the periphery of

the supercooling control member may be considered to be a single-turn secondary of an RF transformer, and the wall of the slot a resistance heater, the two being connected together at the gap 19 in the side wall. Of course, the RF coil 15 serves as the primary of such a transformer. Since an RF voltage is developed across the outer edges of the gap, the gap should be wide enough to prevent arcing across it.

When the supercooling control member is in the form of a graphite cover, it generally is desirable to make it thicker around its periphery than in its central area where the slot is located. This results in more heat being evolved at the slot than at the outside of the cover. It also may be desirable to make the cover slightly larger in diameter than the crucible to avoid any tendency of the crucible so effectively shielding the cover from the RF magnetic field that sufficient heat may not be induced in the cover. The cover, if desired, can be provided with a plurality of gaps in its side wall, all opening into the central slot, in which case the cover will be divided physically into two or more parts but with the same beneficial result.

Of course, materials other than graphite can be used. Also, since radio-frequency currents flow only around the side walls of the supercooling control member, it is possible to cut material away from the interior portions of that member, where no currents flows, without altering the production of heat, so long as no changes are made within a few millimeters of the vertical wall surface of the control member. Carrying this idea to an extreme, as shown in FIG. 3 the circular side wall of the supercooling control member can be formed from a heavy wire 21 that is bent into a circle, with a short gap 22 between the ends of the wire. Tantalum wire is suitable for this purpose. The end portions of the wire may be turned inward in laterally spaced relation, and they are spot welded to two smallar diameter wires 23 that extend part way across the circle to a T-shape supporting wire 24 spot welded to them and to the main wire, whereby a central slot is formed. This supercooling control member obviously is topologically equivalent to the first one described herein, but with most of its interior area cut away. It will be seen that the induced radio-frequency currents will flow through the main wire 21 around the circle and into the gap and through the smaller parallel wires, thereby producing heat at the center of the member. Although this particular configuration may be a desirable one, it is not to be taken as restricted either in shape or materials, but rather merely indicative of the variations that are possible without departing from the spirit of this invention.

According to the provisions of the patent statues, I have explained the principle of my invention and have illustrated and described what I now consider to represent its best embodiment. However, I desire to have it understood that the invention may be practiced otherwise than as specifically illustrated and described.

I claim:

1. In a furnace, a crucible for containing a molten pool of a material and an induction coil encircling the crucible, the improvement comprising a thermal gradient control member formed of electrical conducting material disposed on top of the crucible and being heated when the induction coil is energized to control the thermal gradient at the top of the molten pool in the crucible, the control member having a circular side wall and a top portion having a central opening overlying the molten pool, the control member having one edge completely severed with a gap extending from the severed edge to the central opening whereby electrical currents induced in the circular side wall flow along the material adjacent the gap and opening to generate heat therein.

2. In a furnace for the preparation of crystalline semiconductor material, a crucible for containing a molten pool of said material, a supercooling control member on top of the crucible to reduce and control the thermal gradient at the top of the pool, a radio-frequency coil encircling the crucible and said member, said supercooling control member having a circular side wall provided with a radial gap and a top overlying the pool, said member also having a central opening in the top communicating with said gap, and said side wall and the top at the gap and opening being continuous and formed from electrical conducting material whereby electrical current induced in the circular side wall flows along the material in the top adjacent the gap and opening and generates heat thereat.

3. In the combination recited in claim 2, said opening in the supercooling control member being a slot extending radially only part way across said member and having an open end at said gap.

4. In the combination recited in claim 2, said supercooling control member being a solid member except for said opening and gap.

5. In the combination recited in claim 2, said supercooling control member having open areas between said central opening and circular side wall.

6. In the combination recited in claim 2, said supercooling control member being formed from wire, to provide a circular side wall with a gap therein, and an elongated U-shaped portion extending diametrically to the other side of the circular side wall and having its ends joined to the side wall at said gap.

7. In the combination recited in claim 2, said circular side wall being formed from a wire curved into a circle with a gap between its ends, and said central opening being formed from laterally spaced wires, connected at one end with said ends of the circular wire, and a metal crosspiece connected to said spaced wires at the opposite end thereof.

References Cited by the Examiner

UNITED STATES PATENTS

2,271,916	2/1942	Denneen et al.	219—10.79
2,809,136	10/1957	Mortimer	23—273
2,956,863	10/1960	Goorissen	23—273
3,058,915	10/1962	Bennett	23—273

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