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APPARATUS FOR PRODUCING CRYSTALS

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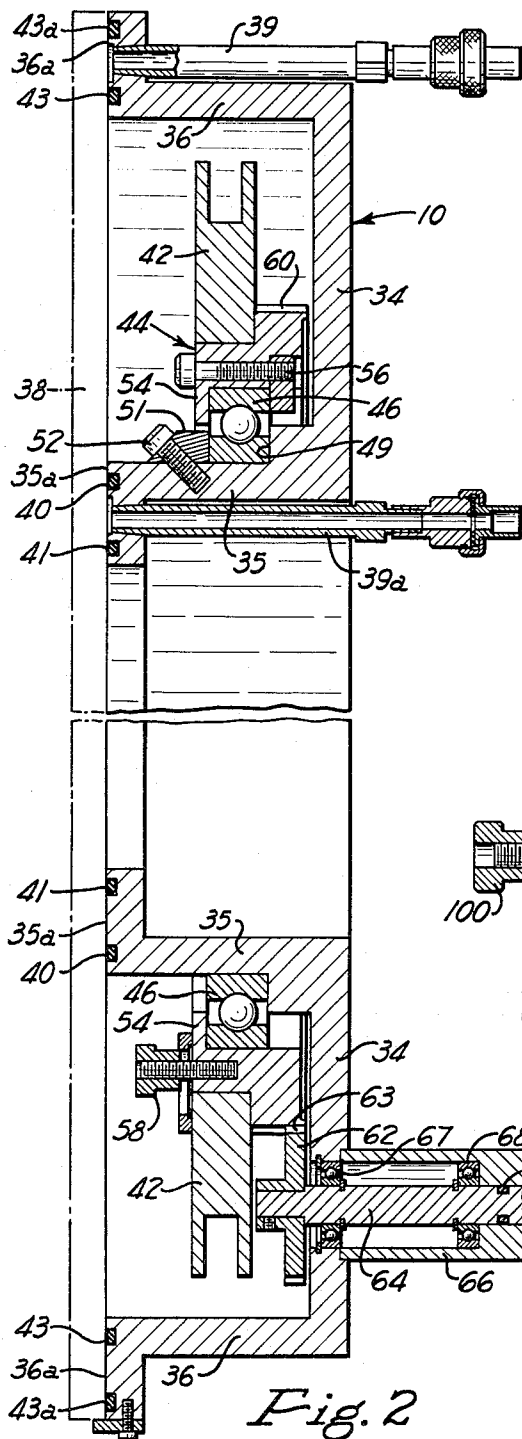


Fig. 2

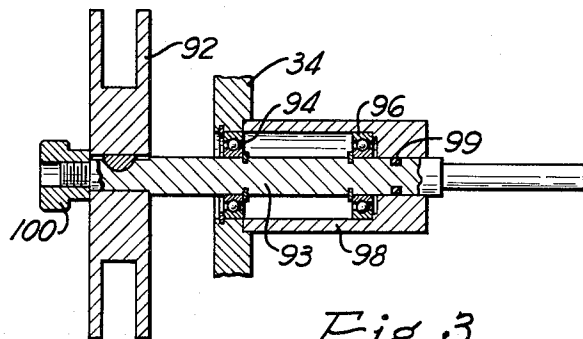


Fig. 3

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APPARATUS FOR PRODUCING CRYSTALS

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This invention relates to a novel furnace combination particularly useful for growing ribbons and other shapes of semiconductor materials from a melt of appropriate materials.

Conventional apparatus is available for producing a crystal of solid material that includes means for contacting the surface of a melt of the material with a previously prepared crystal or seed and slowly withdrawing the prepared crystal. The seed pulls after itself a portion of the melt which solidifies on the seed. In this fashion, an ingot crystal of considerable length, for example 5 to 6 inches, can readily be produced. For many purposes, the crystals produced in conventional apparatus are inadequate and it would be desirable to have crystal strips of any desired length produced under conditions such that the entire product would be essentially a standardized material. It would further be desirable to be able to produce any given size of such material in circumstances whereby the conditions need not be changed and the properties of the product will not change in consequence of the length produced.

Accordingly, it is a principal object of the present invention to provide apparatus for producing semiconductor crystal shapes such as dendritic ribbons or strips of short or extended length, which apparatus is simple in construction and operation, is safer to operate than apparatus heretofore available and by which products of uniform properties are readily obtained.

Other objects will be apparent from the following detailed description taken in conjunction with the drawings:

FIG. 1 is an elevational view, partly in section and with parts broken away, of an illustrative embodiment of the present invention with the cover removed from the storage chamber;

FIG. 2 is a cross-sectional view taken along line II—II of FIG. 1, but to a different scale; and

FIG. 3 is a view taken along line III—III of FIG. 1, but to a different scale.

It will be appreciated that the drawings are adapted for visual clarity and are not to scale. For purposes of describing the drawings, reference will be made to the preparation of dendritic material, but it should be understood that the invention is not to be thereby limited.

Referring now to FIG. 1, the apparatus of the invention comprises a lower or furnace chamber 6 and an upper or reel chamber 10 that are demountably joined through an interconnecting chamber 12. The dendritic or other crystalline semiconductor material is grown in the furnace chamber 6, drawn through the interconnecting chamber 12 and then stored in reel chamber 10.

The typical details of a suitable furnace chamber 6 are evident in FIG. 1, though it should be understood that they form no part of the present invention, and many useful designs for such chambers are available. In the furnace chamber 6 that is illustrated, there is a crucible 14 that can be mounted on a support 15 of suitable material such as graphite. When the support is graphite, it can further serve to electrically ground the crucible member 14. It will be apparent that the support 15 can be made adjustable in any manner desired. The side walls of the furnace chamber 6 are adapted for viewing the crucible area, to permit charging or replacement of the crucible and

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to enable the operator to provide the desired atmosphere, as by drawing a vacuum or admitting a suitable gas. For these purposes, one side wall 16 of the furnace 6 is made of a material such as Pyrex to enable visual control of the work area. A cover plate 18 sealingly engages a second side wall 19 of chamber 6 for ease of charging and discharging the crucible. A demountable port 22 on a third side wall 24 of the furnace 6 can be used for the introduction of a particular atmosphere or the drawing of a vacuum. Of course, suitable valves, gas purifying equipment, vacuum pumps or the like (not shown) would be attached to the port externally of the furnace 6 to carry out such practices. It should be understood that the mountings of the sight glass, cover plate and port are pressure tight.

Spaced about the crucible 14 in the furnace chamber 6 is a heating means 28, which suitably is a metal coil as shown. Generally, radio frequency induction is used to heat the materials in the crucible. Accordingly, heating means 28 normally is used as the primary coil by which a current is induced into the crucible which functions as the secondary coil. A variable power supply (not shown) is attached to the heating coil 28. It will be appreciated that other ways of heating can be used. The temperature of the melt in crucible 14 can be sensed through a means 29, such as a sapphire rod that preferably extends to a position near the melt. The sapphire rod acts in the nature of a wave guide, conducting radiation throughout its length with little or no loss to an indicating means. A system that has been used in conjunction with such a sapphire rod is a thermopile in which the "hot" junctions are located in the path or adjacent the bottom of the sapphire rod and the "cold" junctions are spaced therefrom. The voltage generated thereby, after suitable calibration, readily indicates the temperature conditions in the crucible. This temperature information is used to adjust the heat input to cause solidification, melting or supercooling, depending on the state of the production cycle.

The upper or reel chamber 10 comprises a toroidally shaped chamber that, in the embodiment shown, tapers radially outwardly in one zone to define an enlarged area. The toroid shape is provided by a shell-like chamber defined by a rear wall 34, a generally cylindrical axial wall 35 and an annular wall 36 that parallels the axial wall except where the annular wall tapers outwardly to form the enlarged zone. The ends of the axial wall 35 and the annular wall 36 that are opposite the rear wall 34 are enlarged to provide essentially flat surfaces 35a and 36a respectively that are in a common plane that may be parallel to the rear wall 34. The toroidal chamber is closed by a relatively flat cover member 38 that fits against the flat ends 35a and 36a of the walls 35 and 36. For high pressure practices, as in the use of gallium phosphide, a strong metal cover is used. On the other hand, the cover has been made of a clear plastic, such as Plexiglas or the like, for low pressure operations thereby allowing visual inspection of the chamber during use. The cover may be maintained tightly against the flat ends 35a and 36a of the axial and annular walls 35 and 36, respectively, by means of a series of clamps (not shown) that clip around the edges of it and the cover, or by the drawing of a vacuum or the like. To facilitate a pressure-tight fit, spaced resilient O-rings 40 and 41 are mounted in suitable depressions in the flat end 35a of wall 35 while similar O-rings 43 and 43a are located in the flattened end 36a of the annular wall 36. Tubes 39 and 39a that terminate in the flat ends 35a and 36a between the O-rings 40 and 41 are provided to enable a vacuum closure to be effected. The toroidal shape of chamber 10 with its enlarged zone permits smaller, more rugged construction to be provided for given operating conditions at lesser cost. For example, the absence of waste space in the unit lowers the volume and accordingly, its atmos-

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phere can be controlled, as by being evacuated, more easily than chambers of other shapes. The overall lightweight construction makes handling more convenient also.

Within the upper or reel chamber 10, as is evident in FIGS. 1 and 2, is a wind-up reel 42 supported by a gear wheel 44 that freely rotates on a bearing ring 46. The bearing ring 46 is supported at its inner surface by the axial wall 35 of the chamber 10, and is flush against an abutment 49 of the rear wall 34 of chamber 10. The bearing is held in place by a plurality of metal clips 51, each clip being anchored by a suitable bolt 52 to the axial wall 35.

The gear wheel 44 includes a flange 54 that extends downwardly in front of the bearing ring 46. At spaced locations about the bearing ring 46, the gear wheel 44 is bolted to the ring by nut and bolt units 56 in which the nut is drawn tightly against the rear surface of the outer track of the bearing ring 46 as well as a parallel surface of the gear wheel 44.

The wind-up reel 42 rides on a rim of the gear wheel 44 and is held to it by a plurality of clamp and nut units 58. Thus, the combined annular gear wheel and wind-up reel rotates about the axis of the chamber 10 when force is applied thereto through the teeth 60 of the gear wheel 44.

The reel wheel is rotated by power supplied through a spur gear 62 having its teeth 63 meshing with the teeth 60 of a gear wheel 44. The spur gear 62 is mounted on the inner end of a drive shaft 64 that extends through the rear wall 34 of the reel chamber 10. A bracket 66 supports the drive shaft 64 at spaced bearing rings 67 and 68 along its length. An O-ring 69 on the drive shaft 64 at a point of contact with the bracket 66 prevents communication of the external atmosphere with the reel chamber. An electric motor may be used as the driving means.

The furnace chamber 6 and reel chamber 10 are demountably joined through an interconnecting chamber 12. The interconnecting chamber 12 is composed of three major portions. The first or upper portion is a suitable port or conduit 72 integral with the bottom of the tapered portion of the annular wall 36 and opens into the reel chamber 10. The lower end of the conduit 72 engages the upper surface of a vacuum valve 74 that in turn is integral with a conduit 76 attached to the furnace chamber 6 and opening into it. Any vacuum valve desired can be used provided it can be opened sufficiently to provide a straight, cylindrical opening to permit easy passage of the dendrite or other shape as well as a pull rod. The conduit 76 is hollow and is axially aligned with the melt in crucible 14 in furnace 6. Similarly, the conduit 72 attached to the reel chamber also is hollow and is axially aligned through the valve with the similar conduit 76. The valve 74 and conduits 72 and 76 are flanged so that gaskets can be readily applied to their mating surfaces to keep that part of the structure pressure tight when bolted or otherwise joined in operating relationship.

The growth of dendritic material in accordance with the present invention can be initiated in the same fashion that ingots of single crystalline material are now produced. Thus, a seed is immersed in the supercooled melt of semiconductor material. Then the wet seed is slowly withdrawn whereby portions of the melt solidify on it. For the storage of the material when large lengths of the crystalline material are to be produced, the dendrite strip is wound on the wind-up reel 42. For this purpose, a leader 80 is anchored to the wind-up reel 42 in the storage or reel chamber 10. At its other end, the leader 80 supports and positions the seed crystal at the surface of the melt in crucible 14. A satisfactory manner of attaching the prepared crystal to the leader 80 is by a tape 82. It will be apparent that the wind-up reel 42 is so located with respect to the melt in the crucible 14 that the leader 80 will draw the growing dendrite essentially tangentially to the storage surface of the reel 42. The size of the reel 42 is adapted to present a curvature so

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that the dendrite crystal is bent gently and will lay on the reel surface rather than break.

It is frequently desirable to cover one or both surfaces of the prepared dendrite with a suitable material to provide a measure of protection for it. For this purpose, a self-feeding tape supply reels 90 and 92 are provided in the enlarged zone of chamber 10, one on each side of the opening of conduit 72. These reels generally are identical and therefore but one of them will be described.

A detailed view of tape reel 92 is shown in FIG. 3. The reel 92 is supported on a shaft 93 that extends through the rear wall 34 of chamber 10. The shaft 93 is supported by two bearings, a first bearing 94 being located in wall 34 and the other bearing 96 being held by a bracket 98 through which the shaft 93 extends. At a line of contact with the bracket 98, the tape reel shaft 93 is provided with a resilient O-ring 99 to prevent entry of the atmosphere along the shaft. A thumb nut 100 on the internal end of shaft 93 frictionally bears against the tape reel 92.

In initiating a new run as well as for purposes of making a small quantity of dendrite, a retractable dendrite pull rod 104 is included with the reel chamber 10. The pull rod 104 is aligned with the melt in crucible 14 in the furnace chamber 6, and is supported in a housing 106 communicating with the upper portion of chamber 10 above the enlarged zone thereof. While not shown, the pull rod 104 is supported in the housing, as by the use of packings or O-rings, in a manner that atmosphere control is not lost along its length. Of course, a suitable mechanism, such as a power source, gear train and timer, can be operatively applied to the upper part of the rod to control its movement automatically.

In operation of a furnace combination in accordance with this invention, a semiconductor material such as germanium, silicon or a compound material such as gallium arsenide is placed in the crucible 14 in the furnace chamber 6. With germanium or silicon, the furnace combination can be evacuated by the use of port 112 in the reel chamber or an inert atmosphere may be supplied, preferably through the furnace zone. With gallium arsenide, an atmosphere of arsenic is used in view of the high vapor pressure of the arsenic at the temperature of operation. For gallium phosphide, which exhibits a partial pressure of phosphorus of about 10 atmospheres at the melting point of the compound, the furnace combination must, of course, be pressurized to that extent. The crucible is heated by power passed through the heating coil until the semiconductor material therein is melted. Where a continuous dendrite is to be produced, a seed of the semiconductor material is attached to the leader 80 and with the valve opened and proper conditions of atmosphere provided, this is lowered to the surface of the melt in crucible 14. When the temperature of the melt has been adjusted to supercool it, the seed is wet by the melt and is slowly withdrawn in accordance with conventional procedure. The growing dendrite attached to the leader follows it to the surface of the wind-up reel 42 and is wound thereon. The entire system can be operated automatically, as by fixing the speed of the wind-up reel and then adjusting the temperature of the melt to secure the rate of dendrite growth needed for the wind-up speed chosen. Of course, the system can be operated manually if desired.

When sufficient of the dendrite has been produced or the particular reel is filled, the valve in the interconnecting chamber can be closed to isolate the furnace and storage chambers from one another. Thereupon the storage chamber may be discharged as by removing its cover and withdrawing the dendrite alone or in place with the wind-up reel. In the latter event, a new reel would be substituted and, after replacing the cover, opening the valve and establishing uniform operating conditions, a new run can be initiated.

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Another convenient practice that may be used with this structure is, after closing the valve, the complete demounting of the storage chamber for any purpose desired, for example to use a pull rod by itself. This is possible in view of the demountable joinder of the two main chambers, the association of the valve with the furnace chamber whereby it can be isolated during this change and the compact, relatively light-weight nature of the storage structure that largely is due to its toroidal shape. This practice is particularly useful in view of the fragile character of most dendrites since minimum handling is encountered.

From the foregoing discussion and description, it is evident that our invention provides a unique and highly useful apparatus combination for the preparation of semiconductor shapes. While variations can be made in the device without departing from the scope of the invention, it should be noted that all embodiments of the invention require a generally toroidal shape for the reel chamber. That shape can be as disclosed in the drawings. Alternatively, it can be rounded as desired. It is also possible to use a complete toroid, as distinguished from the modified shape shown. In using a complete toroid, a pipe or conduit through which the semiconductor shape can enter is attached to the toroid as by welding. Tape can be fed to that conduit through auxiliary chambers associated with it.

A particularly important advantage of the shape of the reel chamber of the invention resides in the fact that its volume is a small fraction of the volume of a shell-type or other shaped chamber. The volume of the chamber determines its energy storage capacity and at high temperature-high pressure operation, a shell-type chamber presents a considerable explosion hazard. A toroid shape, on the other hand, greatly minimizes that problem since its volume is so small relative to that associated with other shapes.

In accordance with the provisions of the patent statutes, the invention has been illustrated and described with what is now believed to represent its best embodiment. However, it should be understood that the invention can be practiced otherwise than as specifically illustrated and described.

We claim:

1. Apparatus for the preparation of crystalline semiconductor material comprising a furnace chamber, a crucible mounted within the furnace chamber for containing a melt of said material, means for controlling the temperature of the melt in the crucible, a storage chamber disposed above the furnace chamber, means demountably interconnecting the furnace and storage chambers, wind-up means rotatably mounted within the storage chamber, said wind-up means adapted to receive and store the grown crystalline semiconductor material, said storage chamber consisting of a toroidal shaped end enclosure and a triangular shaped end enclosure, the two end enclosures being jointed together by outer walls of the triangular shaped end enclosure being extended to smoothly blend into the toroidal shaped end enclosure as tangential extensions of the toroidal shaped end enclosure side wall, the triangular shaped end enclosure defining an enlarged zone therein near the means for interconnecting the two chambers, said means for

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interconnecting the chambers mating with the storage chamber at the triangular shaped end enclosures thereof.

2. Apparatus in accordance with claim 1 in which the means demountably interconnecting the furnace and storage chambers includes a vacuum valve whereby the two chambers can be effectively isolated from one another though joined together.

3. Apparatus in accordance with claim 1 including a pull rod vertically aligned with the melt in the crucible in the furnace chamber and the interconnecting means, the rod being mounted in the storage chamber, and means to retract the rod.

4. Apparatus for the preparation of dendritic crystalline material comprising a furnace chamber, a crucible mounted within the furnace chamber for containing a melt of said material, means for controlling the temperature of the melt in the crucible, a storage chamber disposed above the furnace chamber, the storage chamber including a hollow cylindrical center wall and an enclosing wall substantially parallel to the cylindrical wall throughout most of its circumference and tangentially tapering outwardly in the remainder thereof thereby defining an enlarged zone, an enclosing wall integral with the cylinder and its essentially parallel wall and a removable enclosing wall attached to the other surface of the cylinder and its parallel wall, and means for demountably interconnecting the furnace and storage chambers.

5. Apparatus in accordance with claim 4 in which said means for interconnecting the chambers includes a vacuum valve.

6. Apparatus in accordance with claim 4 including in the storage chamber a vertically movable rod aligned through the interconnecting means with the melt in the crucible in the furnace chamber, and means to move that rod vertically.

7. Apparatus for the preparation of crystalline semiconductor material comprising a furnace chamber, a crucible mounted within the furnace chamber for containing a melt of said material, means for controlling the temperature of the melt in the crucible, a storage chamber disposed above the furnace chamber, means demountably interconnecting the furnace and storage chambers, and wind-up means rotatably mounted within the storage chamber, said storage chamber consisting of a toroidal shaped end enclosure and a triangular shaped enclosure, the two end enclosures being joined together by outer walls of the triangular shaped enclosure being extended to smoothly blend into the toroidal shaped end enclosure as tangential extensions of the toroidal shaped end enclosure.

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