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3,228,753

ORBITAL SPIN CRYSTAL PULLING

Filed July 27, 1962

2 Sheets-Sheet 1

FIG. 2

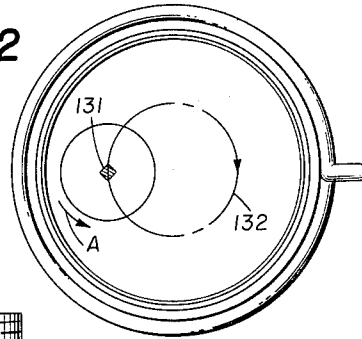


FIG. 1

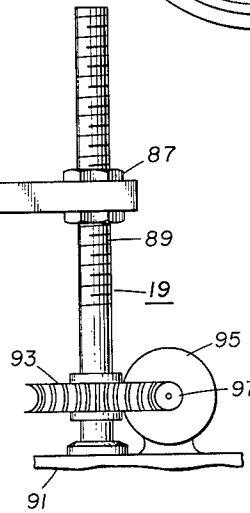
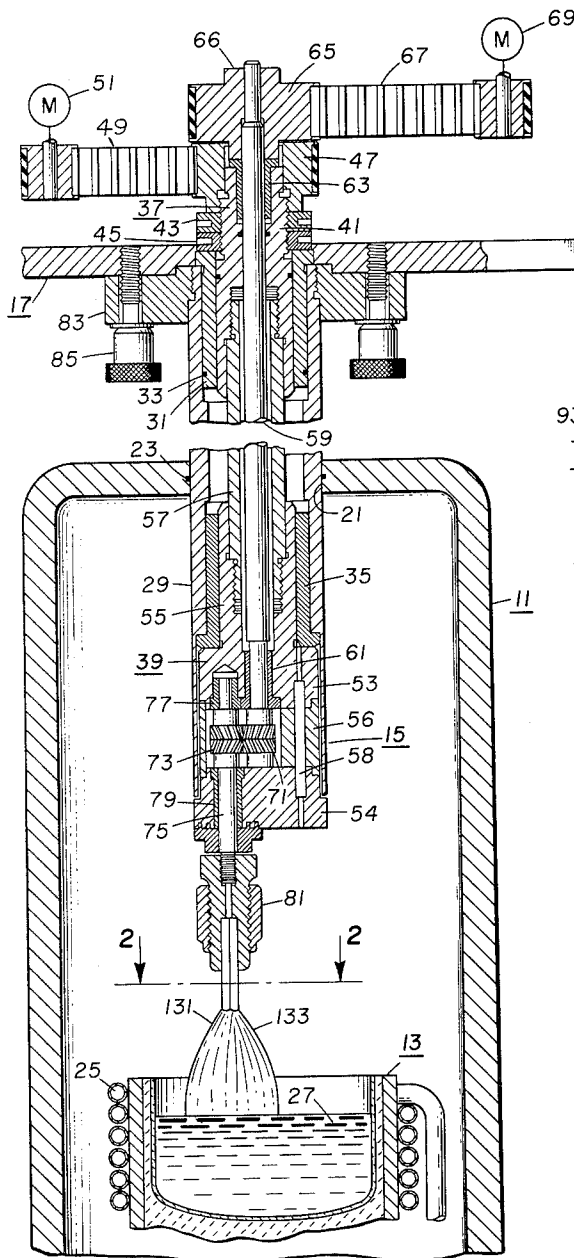


FIG. 4

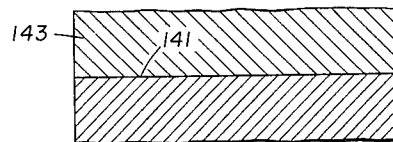
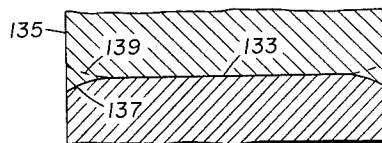


FIG. 3



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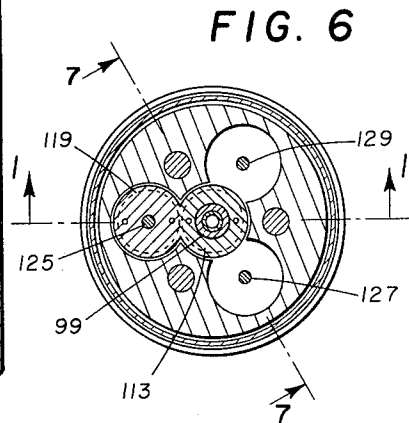
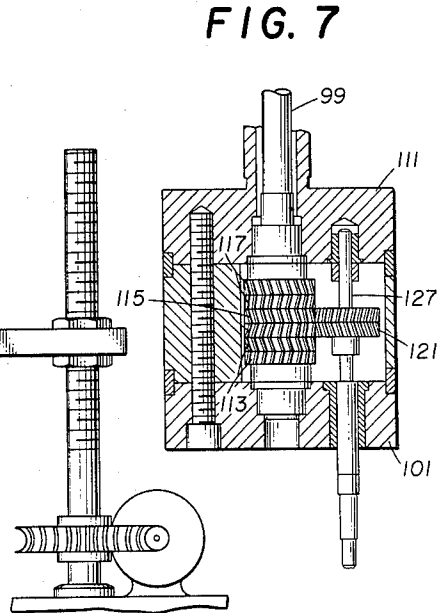
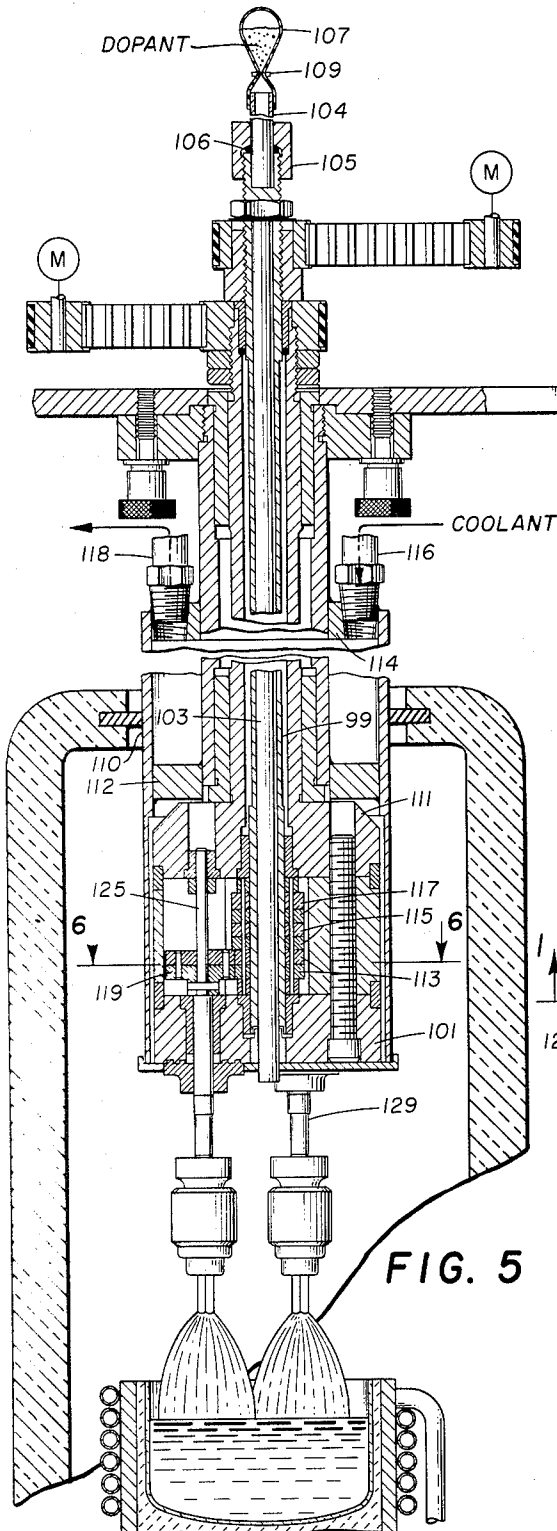
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ORBITAL-SPIN CRYSTAL PULLING

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11 Claims. (Cl. 23—273)

This invention relates to crystal growth and more particularly to a system for moving a seed crystal relative to a melt of crystal material in such a manner that an improved semiconductor crystal is produced.

Crystals for semiconductor use are required to have controlled electrical characteristics. Several methods have been developed for growing single crystal bodies which approach the necessary requirements. However, prior art techniques are not entirely satisfactory for producing crystals. Indicative of the problem is the shape of grown junctions produced by techniques of the prior art. Such crystals have a junction that is curved or dished much like a meniscus. It is not unusual to find in both single resistivity, vertically grown crystals and grown junction crystals, which are produced by prior art techniques, an excessive variation in resistivity in the radial and axial directions of the crystal. Furthermore, it is generally recognized that to pull a single resistivity crystal or a grown junction crystal having the required characteristics is difficult.

In accordance with the present invention, there is provided a system for growing improved semiconductor crystals. A crystal seed body is supported for rotation about its axis at a predetermined speed while in contact with a semiconductor melt. Simultaneously therewith, the support is moved in an orbital path having a center spaced from the axis of rotation. Synchronously, the seed crystal is moved upward away from the melt to achieve growth. If desirable, a dopant substance may be introduced into the melt to produce a crystal having regions of different characteristics separated by a grown junction or interface. A crystal produced in accordance with the method disclosed herein has a significantly greater degree of uniformity than was obtainable heretofore.

It is an object of the present invention to provide a system for facilitating the production of improved semiconductor crystals.

An object of the invention is to provide a system for producing a grown junction crystal which has a substantially planar interface between the doped and undoped portions thereof.

Another object of the invention is to provide a system for producing a grown junction crystal which has controlled and constant resistivity characteristics.

A further object of the invention is to provide a system for producing simultaneously a plurality of improved semiconductor crystals in accordance with each object set forth hereinbefore with respect to a single crystal.

More particularly, in accordance with the present invention, there is provided a system for growing improved semiconductor crystals. A crystal seed is supported by and maintained in a suitable apparatus adapted for movement toward and away from the surface of a liquid melt of semiconductor material. Such melt is contained in a crucible within an inert gas-filled chamber. The apparatus is adapted to penetrate sealably the chamber and to rotate each crystal axially. Simultaneously therewith, the apparatus moves the crystal in an orbital path having a radius substantially greater than the radius of the crystal to be grown. Synchronously with such movements, the apparatus is moved away from the melt to achieve crystal growth.

For a more complete understanding of the invention and for further objects and advantages thereof, reference may now be made to the following description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a longitudinal sectional view of a system for pulling a grown junction crystal in accordance with a preferred method of the invention;

FIGURE 2 is a sectional view taken along line 2—2 of FIGURE 1;

FIGURE 3 is a fragmentary longitudinal sectional view of a typical interface of a crystal formed in accordance with prior art techniques;

FIGURE 4 is a fragmentary longitudinal sectional view of a typical interface of a crystal formed in accordance with a preferred method of the present invention;

FIGURE 5 is a longitudinal sectional view of a modified apparatus forming a part of a system for pulling a plurality of grown junction crystals;

FIGURE 6 is a sectional view taken along line 6—6 of FIGURE 5; and

FIGURE 7 is a sectional view taken along line 7—7 of FIGURE 6.

Referring now to FIGURE 1, there is illustrated a system for facilitating the production of semiconductor crystals of high uniformity. The system includes a gas-tight chamber 11 (partially shown) wherein there is a crucible 13. A crystal puller 15 extends into the chamber 11 and is mounted on a support structure 17. A mechanism 19 selectively raises and lowers the crystal puller 15.

The chamber 11 is a hollow container of any suitable shape which is provided with an opening 21 in the top of sufficient size slidably to receive the body of the crystal puller 15. The chamber 11 is provided with an O-ring seal 23 in the opening 21 to maintain a gas-tight seal around the body of the crystal puller 15. The crucible 13 is supported within the chamber 11 and is of a type well-known in the art. It is provided with a suitable heating element 25 to heat and melt a selected quantity of semiconductor material 27. The molten semiconductor material 27 hereinafter will be referred to as the melt 27.

The crystal puller 15 includes a cylindrical body or tube 29 having one end fixedly mounted in the movable support structure 17, while the other end is disposed within the chamber 11, above the surface of the melt 27. The axis of the tube 29 is perpendicular to the surface of the melt 27. Adjacent the mounted end of the tube 29 there is provided a bearing or bushing 31 which has an O-ring seal 33 adjacent the lower end thereof. Another bearing or bushing 35 is provided within the tube 29 near the lower end thereof. Both of the bearings 31 and 35 are concentric with the axis of the tube 29 and are adapted to receive, respectively, an upper driving mechanism 37 and a lower driven mechanism 39. The upper mechanism 37 includes a hollow tubular cylinder 41, the lower portion of which rotates in the bearing 31 while the upper portion projects above the upper end of the bearing 31. A pair of thrust bearings 43, 45 are secured to the upper portion of the cylinder 41 and bear against the upper end of the bearing 31. A pulley 47 is fixed adjacent the end of the cylinder 41 above the bearings 43, 45 for the purpose of rotating the cylinder 41. The pulley 47 is adapted to be driven, preferably, by a flexible belt 49, of the type having teeth on one side, from a motor 51.

In the lower end portion of the tube 29 is a cylindrical head 53 integrally formed with a neck 55 which is journaled in the bearing 35. A hollow cylindrical tube 57 threadably engages the lower and upper ends, respectively, of the cylinder 41 and the neck 55. The tube 57, therefore, provides an effective rotational link between the pulley 47 on the cylinder 41 and the head 53. Another

head 54, having an outer diameter substantially equal to the tube 29, is maintained in fixed spaced relation to the head 53 by a suitable spacer 56 and a plurality of fasteners (not shown) adapted to fit in the holes 58. Within the tube 57, there is provided a shaft 59 which is journaled adjacent its lower end in a bearing 61 in the head 53. The upper end of the shaft 59 is journaled in a bearing 63 in the upper end region of the cylinder 41. The upper end of the shaft 59 is provided with pulley 65 which is keyed to the shaft 59 and secured thereon by a nut 66. Pulley 65 is driven by a belt 67, preferably of the same type as the belt 49, from a motor 69. The lower extremity of the shaft 59 projects below the head 53 and a herringbone gear 71 is mounted thereon. The gear 71 meshes with another herringbone gear 73 mounted on a shaft 75 which is journaled in bearings 77 and 79 in the heads 53 and 54, respectively. The shaft 75 projects downward through the bottom of the head 54 and supports a chuck device 81.

The upper end of the tube 29 threadedly engages a ring 83 which is secured to the support structure 17 by a plurality of knurled screws 85. The support structure 17 is adapted to move readily upward and downward on suitable guides (not shown) by actuating the raising and lowering mechanism 19. This mechanism is diagrammatically illustrated as including a suitable follower 87 secured to the structure 17. Follower 87 engages a vertically disposed screw 89. This screw 89 engages a thrust bearing at its lower extremity on a fixed support 91. A gear 93 is mounted on screw 89 and is driven by a motor 95 and a worm 97.

The apparatus of FIGURE 1 is adapted to pull one crystal, whereas the apparatus of FIGURE 5 is adaptable simultaneously to pull three crystals. However, because the structure of the modification shown in FIGURE 5 is similar in many respects to the structure of FIGURE 1, the structure of FIGURE 5 will be described primarily in terms of aspects essentially different from FIGURE 1.

In FIGURE 5 a shaft 99 is provided which extends into a lower head 101 and which has a center bore 103 throughout its entire length. A tube 104, preferably of quartz, is supported in the bore 103. The shaft 99 is provided, also, with a nut 105 and an O-ring 106 which may be variably compressed to form a seal around the tube 104. The tube 104 is of length sufficient to traverse the bore 103 with the lower end adjacent the surface of the melt and the upper end a slight distance above the nut 105. A sac 107 preferably of suitable flexible plastic, is sealably secured to the upper end of the tube 104. Dopant material stored in sac 107 may be introduced into the melt. A releasable clamp 109, of any appropriate type, is applied to the neck of the sac 107 to retain material therein until it is to be released.

Additionally, a water jacket 110 surrounds the body of the puller. The jacket 110 is sealed at the lower and top ends, respectively, by collars 112, 114 welded or otherwise suitably attached to the puller body and the cylinder 110. A water inlet fitting and hose 116 and an outlet fitting and hose 118 are provided in the top collar 114 for purposes of circulating a coolant in the jacket 110.

Between the upper head 111 and the lower head 101 there are three sets of herringbone gears 113, 115, 117 disposed in stacked array, all mounted on the shaft 99. There is provided, also, three other sets of herringbone gears 119, 121, 123, mounted on shafts 125, 127, 129 respectively. The upper end of each shaft 125, 127, 129 is journaled in the upper head 111, while the lower end is journaled in the lower head 101 and projects therethrough. It will be noted from FIGURES 5 and 7 that the gear 119 is disposed to mesh with the gear 113; that the gear 121 is disposed above the level of gear 119 so that it will mesh with the gear 115; and, though not so shown, that the gear 123 is disposed above the level of gear 121 so as to mesh with the gear 117. By this construction separate

gear drive arrangements are provided for each of the shafts 125, 127 and 129. Each gear may establish its own wear pattern. The motional variations otherwise present are avoided by individual driving linkages for each shaft.

In operation of FIGURE 1, a seed crystal 131 is inserted in and held firmly by the chuck device 81. The tube 29 is inserted into the chamber 11 until the crystal 131 is close to the melt 27. The crucible will at this time have been charged with a selected quantity of semiconductor material that is melted by heat from the heater element 25. The chamber 11 will have been filled with an inert gas, preferably helium, and is maintained in such state to prevent any possibility of oxygen contaminating the melt and the crystal as it is being pulled. Thereafter, the apparatus is lowered until the seed crystal 131 contacts the melt. The motor 69 is then energized to set the crystal to spinning about its own axis, indicated generally by the arrow A of FIGURE 2. Simultaneously, the motor 51 is energized to provide movement of the crystal 131 about the axis of the shaft 59, in an orbital path 132 of FIGURE 2. Thereafter, the motor 95 may be energized, whereupon the support structure 17 and the apparatus move upward. The raising and lowering mechanism 19 (or pull mechanism) is adapted, as is known in the prior art, to be operated at variable speeds. When pulling a crystal, it is operated at a relatively slow speed to pull or move the seed crystal 131 away from the melt 27, thus allowing the crystal to "grow."

In operation of the system of FIGURE 5, it is to be understood that the apparatus operates in an atmosphere of helium as in a chamber such as chamber 11 containing a crucible 13 and a melt 27. Three seed crystals (not shown) are introduced into the melt in the same manner as crystal 131. The three crystals are rotated axially, orbited and moved away from the melt. If it is desirable to create grown junction crystals, the quartz tube 104 may be lowered in the tube 99 until the end of the tube 104 is adjacent the surface of the melt. Thereafter the clamp 109 is released to allow a dopant substance, which may be any of several that are well-known in the art, to flow from the sac 107 down the tube 104 and into the melt. The quartz tube 104 is then retracted to its initial position away from the melt. Immediately the dopant mixes with the melt, an interface forms in the crystal between the undoped upper portion and the doped lower portion. Pulling, of course, continues until either crystals of desired length are produced or all of the melt is exhausted.

Whether a single crystal or a plurality of crystals are to be produced, the speed of axial rotation and the direction thereof are variable. The speed and the direction of orbiting also may be variable. It will be apparent that a crystal may, if desired, be rotated in the same direction that it orbits; it may be rotated in the opposite direction to the orbit; or it may oscillate about its axis while it orbits. A preferred embodiment of the invention is indicated by FIGURE 2 where the orbital rotation is counter to that of the axial rotation of the crystal. In this manner, the combination of the rotational and orbital direction and speed with the movement away from the melt serves to permit fine control over the character of the crystalline structure, producing crystals of uniformity not heretofore possible.

A significant feature of the present invention is that all portions of the growing crystals pass through all temperature gradients of the melt, because they are orbited within the crucible.

Another feature of the present invention is that an orbiting and rotating body agitates the melt in such a manner that a pattern favorable to equalizing temperatures and minimizing gradient extremes is achieved.

Another feature of the present invention is that orbiting and simultaneous rotation agitates the melt so that the dopant is more uniformly distributed through the melt.

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Yet another feature of the present invention is that the seed crystals are rotated about an axis which is more nearly concentric and perpendicular to the surface of the melt, with the result that the planes of the grown crystals are more nearly the required angular relationship to the crystal configuration.

It has been found that grown junction crystals produced in accordance with the method of the present invention, which is described hereinbefore, achieve a degree of uniformity not heretofore obtainable by using methods of the prior art. The interface of the grown junction crystals produced by the method of the present invention is substantially planar, as shown in FIGURE 4. Whereas, as shown in FIGURE 3, the interface 133, of a crystal 135 produced in accordance with methods of the prior art, is dishd. The junction interface 133, while substantially planar over a portion of the crystal cross section, is characterized by curved boundaries 137, 139 not unlike those found in concave and convex menisci. While in the production of grown junction devices relatively short crystals are produced in order to secure the junction slice therefrom, the more general use of grown crystals is for the production of semiconductor bodies of uniform and predetermined crystal orientation, so that they may be employed as substrates for semiconductor devices produced other than by the grown junction technique. For example, semiconductor devices produced by means of epitaxial growth require, for reliable operation, the availability of crystals having highly uniform crystal structures. For this reason, it has been found that substantial loss in crystal material is experienced when the crystal structure is formed with inhomogeneities as are indicated by the formation of curved interfaces 137, 139 of FIGURE 3.

In accordance with the present method of growing crystals, uniformity can be achieved such that, in a grown junction device, the junction has been found to be substantially planar, as indicated in FIGURE 4. The junction 141 will be seen to extend horizontally across the entire width of the crystal 143. Furthermore, by proper control of temperature, speed of rotation, speed of orbit, and other factors involved in crystal pulling operations, not only may the junction 141 be formed in a planar fashion, but the curvature in the manner as indicated by the curves 137 and 139 of FIGURE 3 may also be achieved. The latter structure indicates that the crystal structure may be controlled to avoid the prior art problems and that the degree of control can be selected. In general, the uniformity indicated in FIGURE 4 represents the desired objective.

Having described the invention in connection with certain embodiments thereof, it is understood that further modifications may suggest themselves to those skilled in the art and it is intended to cover such modifications as fall within the scope of the appended claims.

What is claimed is:

1. A system for producing grown semiconductor crystals which comprises:

- (a) a gas-tight chamber containing a quantity of inert gas,
- (b) a crucible within said chamber containing a semiconductor melt,
- (c) a seed crystal,
- (d) apparatus for holding the extremity of said seed crystal in contact with said melt,
- (e) means in said apparatus to rotate said crystal about an axis of said crystal and for simultaneously moving said crystal in an orbital path having a center spaced from said axis, and
- (f) means for moving said apparatus and said crystal in direction away from said melt.

2. A system for producing grown junction semiconductor crystals which comprises:

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- (a) a gas-tight chamber containing a quantity of inert gas,
- (b) a crucible within said chamber for containing a semiconductor melt,
- (c) a seed crystal,
- (d) apparatus for holding said seed crystal in contact with said melt,
- (e) means for rotating said seed crystal about an axis and for simultaneously moving said crystal in an orbit having a center substantially removed from said axis,
- (f) means for moving said seed crystal away from said melt, and
- (g) means for introducing a dopant substance into said melt.

3. A system for producing on a seed crystal a semiconductor body from a liquid semiconductor melt which comprises:

- (a) a housing for said melt containing an inert gaseous atmosphere,
- (b) crystal seed support apparatus in said housing,
- (c) means in said apparatus for rotating said support about an axis and for simultaneously moving said crystal in an orbital path having a center displaced laterally from said axis, and
- (d) means for moving said apparatus toward and away from said melt to immerse said crystal seed therein and withdraw the same therefrom to build said body on said seed crystal.

4. A system for producing on a seed crystal a semiconductor body from a liquid semiconductor melt which comprises:

- (a) a housing for containing an inert gaseous atmosphere,
- (b) a seed crystal support apparatus extending downward through the top of said housing for immersing said seed crystal in said melt,
- (c) means for rotating said apparatus about a first vertical axis and for simultaneously actuating said apparatus to move said crystal in an orbital path centered on a second axis substantially parallel to but spaced from said first axis, and
- (d) means for moving said apparatus away from said melt.

5. A system for producing from seed crystals a plurality of grown semiconductor bodies from a semiconductor melt maintained in an inert gaseous atmosphere, which comprises:

- (a) a plurality of seed crystal holders disposed in an array about a central axis,
- (b) means for rotating said holders on their respective axes and for simultaneously actuating said array about said central axis to orbit said seed crystals while they rotate, and
- (c) means for moving said array toward and away from said melt to establish contact with said melt and to build said bodies thereon by withdrawal therefrom.

6. The combination set forth in claim 5 in which three holders are uniformly disposed along an orbital path and are independently rotationally driven from a common drive element.

7. A system for producing on a seed crystal a semiconductor body grown in an inert gaseous atmosphere from a semiconductor melt which comprises:

- (a) a cylindrical housing extending into said gaseous atmosphere and above said melt having a central shaft therein,
- (b) a sleeve encompassing said shaft,
- (c) an idler shaft means supported by said sleeve and extending below said central shaft and said sleeve and including means to support said seed crystal therebelow,

- (d) a gear train coupling said central shaft to said idler shaft means in driving relation,
- (e) means for rotating said central shaft to cause the support means to rotate about an axis spaced from the axis of said central shaft, 5
- (f) means for rotating said sleeve to orbit said support means about the axis of said central shaft, and
- (g) means for driving said housing toward and away from said melt to bring said seed crystal into contact with the surface of said melt and to withdraw the same therefrom to build said body thereon. 10
8. A system for producing on seed crystals semiconductor bodies grown in an inert gaseous atmosphere from a semiconductor melt which comprises:
- (a) a cylindrical housing extending into said gaseous atmosphere above said melt and having a cylindrical shaft therein, 15
- (b) a sleeve encompassing said shaft,
- (c) an array of idler shafts supported by said sleeve and extending below said housing, each shaft having means to support a seed crystal therebelow, 20
- (d) gears coupling said cylindrical shaft to said idler shafts in driving relation,
- (e) means for rotating said central shaft to rotate the support means about the axes thereof which axes are spaced from the axis of said cylindrical shaft, 25
- (f) means for rotating said sleeve to orbit said support means about said axis of said central shaft, and
- (g) means for driving said housing toward and away from said melt to bring said seed crystals into contact with the surface of said melt and to withdraw the same therefrom simultaneously to build said separate ones of said bodies on said seed crystals. 30
9. The combination set forth in claim 8 in which said gears include three separate driving gears stacked one above the other on said cylindrical shaft and a driven gear mounted on each of said idler shafts with each driven gear engaging a different one of the driving gears. 35
10. The combination set forth in claim 8 in which structure forming fluid flow channels lead to and from the interior of said cylindrical housing for coolant flow through said housing. 40
11. A system for producing on a seed crystal a semiconductor body grown from a semiconductor melt which comprises:
- (a) structure forming an enclosure for said melt and

- containing an inert gas therein, said enclosure having a cylindrical opening vertically above said melt,
- (b) a cylindrical housing extending through said opening having a central shaft therein,
- (c) means for maintaining a gas-tight seal in said opening between said enclosure and the wall of said housing,
- (d) a sleeve encompassing said shaft,
- (e) an idler shaft mounted for movement with said sleeve and extending below the ends of said central shaft and said sleeve and having means to support said seed crystal therebelow,
- (f) a gear train connecting said central shaft to said idler shaft in driving relation,
- (g) means for rotating said central shaft to cause the support means to rotate about an axis spaced from the axis of said central shaft,
- (h) means for rotating said sleeve to orbit said support means about the axis of said central shaft, and
- (i) means for controllably moving said system toward and away from said melt to bring said seed crystal into contact with the surface of said melt and to withdraw the same therefrom to build said body thereon.

References Cited by the Examiner

UNITED STATES PATENTS

2,727,839	12/1955	Sparks	23—301
2,808,239	10/1957	Reiffen	259—102 XR
2,931,232	4/1960	Martin	259—102 XR
2,935,385	5/1960	Cornelison	23—273
2,950,219	8/1960	Pohl	148—1.5
2,973,290	2/1961	Mlavsky	148—1.4
2,975,036	3/1961	Taylor et al.	23—273
2,979,386	4/1961	Shockley et al.	23—273

OTHER REFERENCES

- Lehovec et al.: "Apparatus for Crystal Pulling in Vacuum using a Graphite Resistance Furnace," Review of Scientific Ins., vol. 24, #8, August 1953, pages 652-655.
- Hannay: Semiconductors, Reinhold Publ. Corp., Feb. 27, 1957, pages 101-110.

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