

Oct. 23, 1962

T. H. OREM
METHOD FOR THE GROWTH OF PREFERENTIALLY
ORIENTED SINGLE CRYSTALS OF METALS

3,060,065

Filed Aug. 6, 1959

3 Sheets-Sheet 1

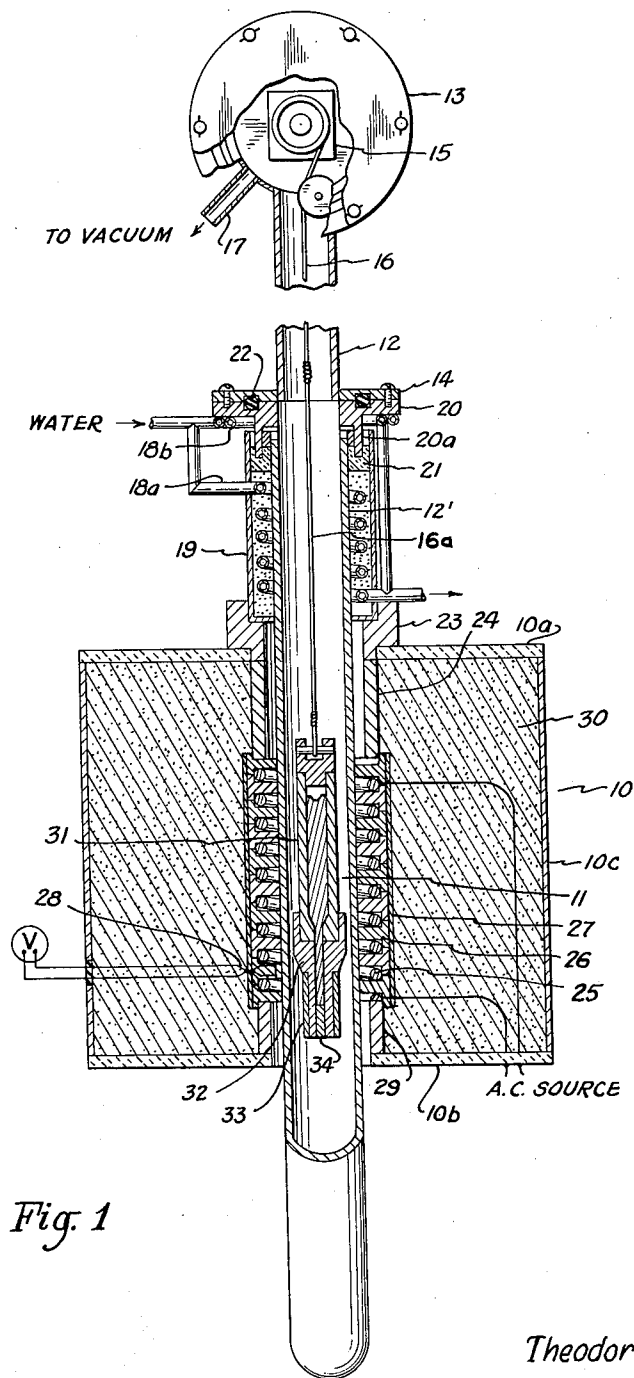


Fig. 1

INVENTOR

Theodore H. Orem

BY

Arthur Vinograd
John C. Stahl

ATTORNEYS

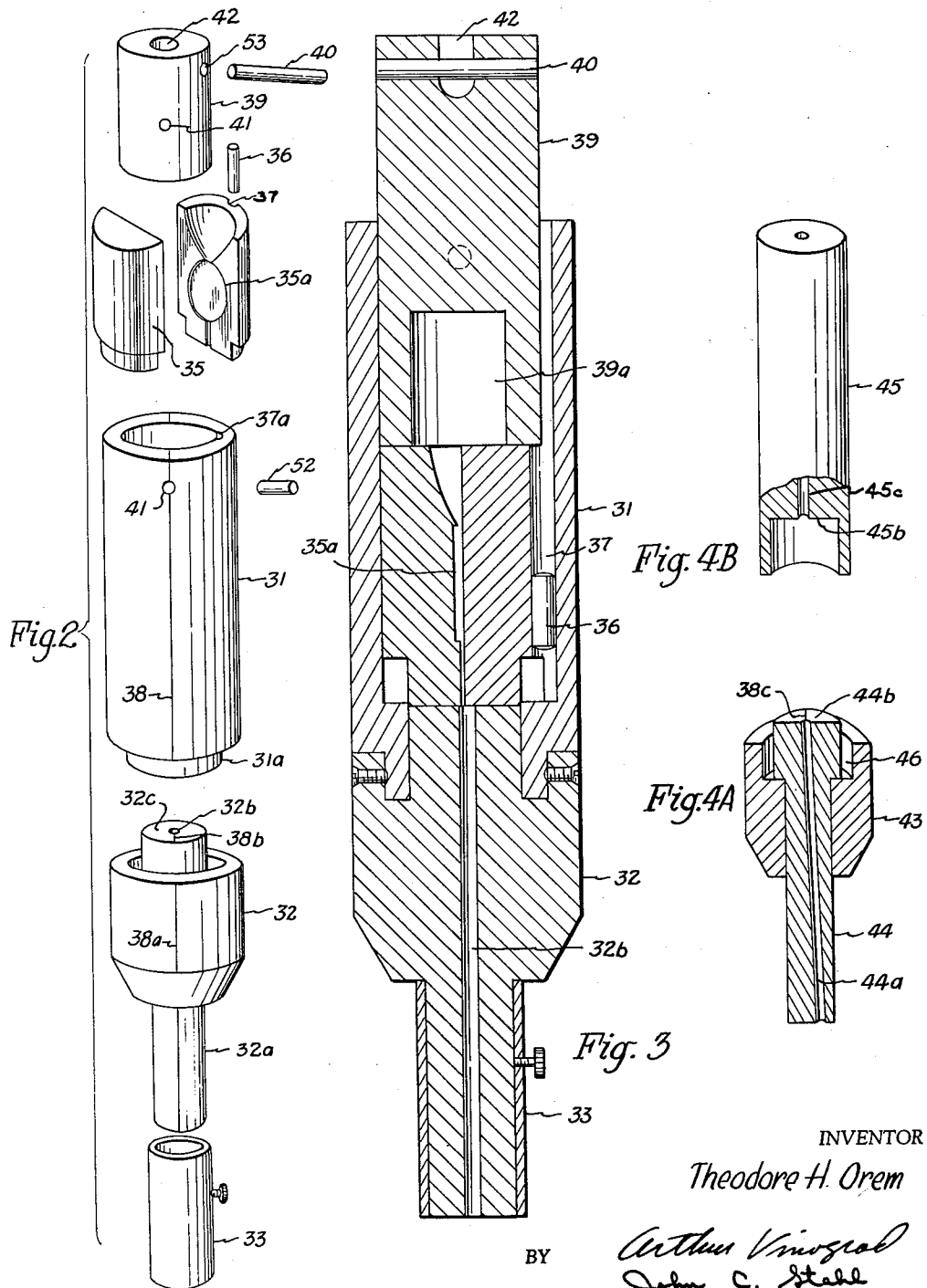
Oct. 23, 1962

T. H. OREM
METHOD FOR THE GROWTH OF PREFERENTIALLY
ORIENTED SINGLE CRYSTALS OF METALS

3,060,065

Filed Aug. 6, 1959

3 Sheets-Sheet 2



INVENTOR

Theodore H. Orem

BY

Arthur Vinograd
John C. Stahl

ATTORNEYS

Oct. 23, 1962

T. H. OREM
METHOD FOR THE GROWTH OF PREFERENTIALLY
ORIENTED SINGLE CRYSTALS OF METALS

3,060,065

Filed Aug. 6, 1959

3 Sheets-Sheet 3

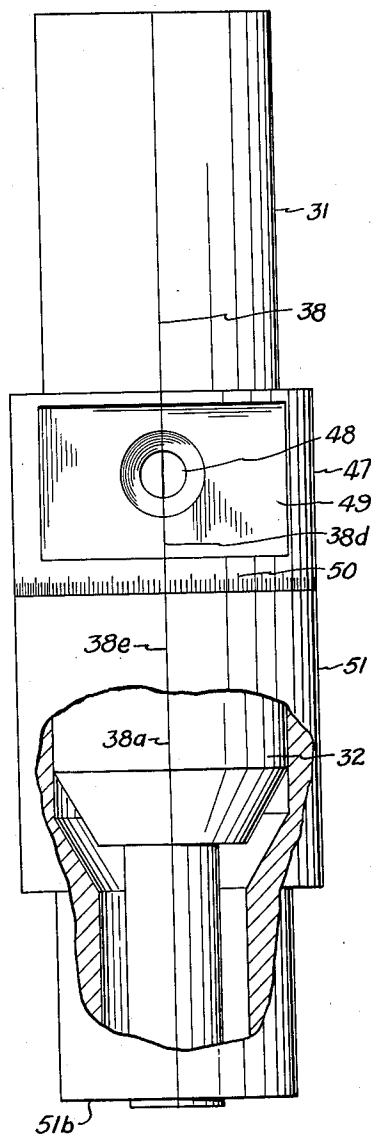
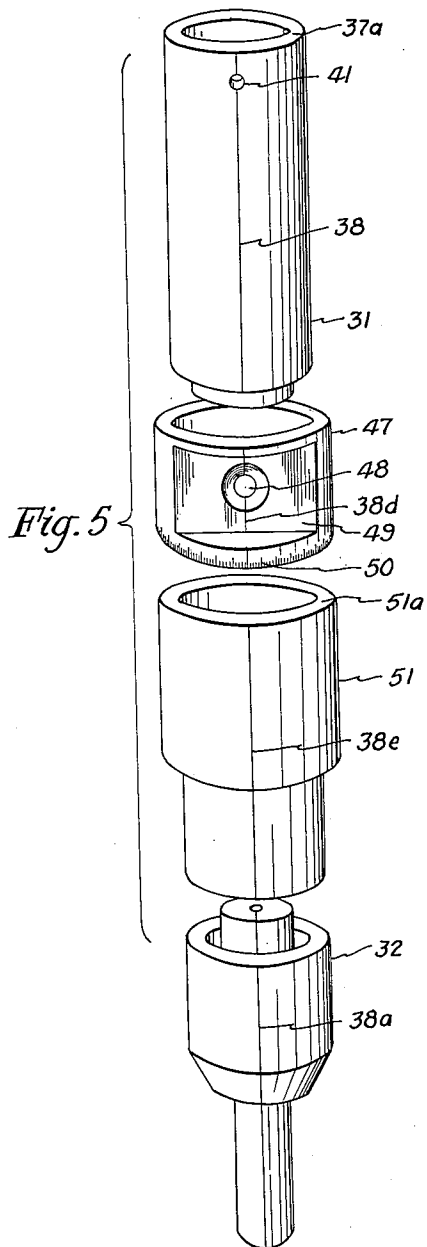


Fig. 6

INVENTOR

Theodore H. Orem

BY

Arthur Vinograd
John C. Stahl
ATTORNEYS

1

3,060,065

METHOD FOR THE GROWTH OF PREFERENTIALLY ORIENTED SINGLE CRYSTALS OF METALS

Theodore H. Orem, Silver Spring, Md., assignor to the United States of America as represented by the Secretary of Commerce

Filed Aug. 6, 1959, Ser. No. 832,127

3 Claims. (Cl. 148-1.6)

The present invention relates to a method for producing metallic monocrystals of a preferred axial orientation and more particularly to growing monocrystals of metals with any desired axial orientation and external configuration.

Single crystals of metals are widely used in fundamental research on metals. It is often desirable that single crystals have a definite atomic arrangement, either in their surfaces or in certain crystallographic directions within the specimen. Heretofore, difficulty has been experienced in producing specimens having a preselected crystallographic orientation in combination with a desired external configuration.

The internal structure of a crystal as revealed by X-ray diffraction measurement demonstrates planes which contain relatively large numbers of atoms. It is possible to identify these internal planes by reference to imaginary coordinate axes. These axes define a framework, or lattice, that is fundamental to the description of the crystal structure.

For purposes of explanation throughout the body of the specification the term horizontal plane of atoms will refer to a specific horizontal plane of atoms having the desired axial orientation whereas the term vertical plane of atoms will refer to a specific vertical plane of atoms having the desired vertical axial orientation as determined by conventional X-ray diffraction methods. See Crystals and X-rays by K. Lonsdale, pages 50-80.

To a certain degree monocrystals of a preferred axial orientation may be produced by a method generally known as seeding. This procedure is described in Bridgman Patent No. 1,793,672, wherein a vertical furnace is employed together with a seed crystal of desired horizontal and axial orientation. In this procedure, the seed, a small, single crystal of the same material as the specimen to be produced, is mounted in a position against a polycrystalline specimen. By using a suitable furnace, the heating conditions are then adjusted so that the entire charge, with the exception of a small portion of the seed crystal, becomes molten. By properly controlling the rate of withdrawal of the melt from the hot zone of the furnace, the molten plane is allowed to freeze progressively from the seed and the new single crystal will have a horizontal orientation identical with that of the seed. However, in order to control the direction of the horizontal plane of atoms as in Bridgman, it is necessary, in the first place, to start with a seed crystal of the desired horizontal axial orientation. The seed may be selected from a large number of single crystal castings of small diameter which has the desired axial orientation. Furthermore, it is to be noted that the crystal produced by this prior art method contains a horizontal plane of atoms parallel to the plane of atoms within the seed crystal only, orientation along a desired or specific vertical plane of atoms within the specimen occurs merely by chance.

2

It is therefore an object of this invention to produce metallic monocrystals of a preferred axial orientation.

A more specific object of this invention is to prepare monocrystals of metals having any desired axial orientation and of any external configuration.

Another object of this invention is to provide means for changing the axial orientation of a seed crystal.

Other uses and advantages of the invention will become apparent upon reference to the specification and drawings in which:

FIG. 1 is a front view, partly in section, of a suitable type of vertical furnace in which metallic monocrystals of this invention may be produced showing the position of the improved crucible employed in connection with this invention;

FIG. 2 is an exploded view of the crucible assembly of this invention showing the relative positions of parts preparatory to assembly;

FIG. 3 is a vertical sectional view of the crucible assembly of FIG. 2;

FIG. 4A is a vertical sectional view of a modified seed receptacle;

FIG. 4B is an isometric view of an aligning mold to be used with the modified seed receptacle of FIG. 4A for modifying the axial orientation of a seed crystal;

FIG. 5 is an exploded isometric view of an aligning fixture employed in connection with this invention preparatory to assembly, and

FIG. 6 is a side elevational view of the assembled aligning fixture of FIG. 5 showing the crucible in position.

The Furnace

Referring to the drawings, there is shown in FIG. 1 a furnace 10 which may be employed in connection with the invention. The complete crucible assembly 11, diagrammatically illustrated in FIG. 1 of the drawings and hereinafter to be discussed more fully in connection with FIGS. 2 and 3, is lowered through a chamber formed by tubes 12-12' into the heating zone of the furnace 10. The upper end of guide tube 12 connects in a conventional manner with a sealed chamber 13. The lower end of tube 12 is integral with a plate 14. Guide tube 12 and plate 14 are preferably constructed of brass or the like. The composition of tube 12' depends upon the melting point of the crystal to be produced. For example, in preparing single crystals of aluminum (M.P. 660° C.) quartz tubes are used. These tubes can be used to temperatures of approximately 900° C. without softening or appreciable devitrification. Alumino-silicates such as mullite can be used to 1,500° C., pure alumina to 1,900° C. and zirconia and thoria to 2,200° C. A constant speed motor 15 is mounted within chamber 13 and it attached by means of a flexible metallic cable 16 and Inconel extension 16a with assembly 11 and controls the rate at which the crucible traverses the furnace. Preferably, a rate of travel of the crucible 11 through the furnace at approximately one-half inch per hour is maintained. A conduit 17 connects the sealed chamber 13 to a vacuum source in order to reduce the pressure within the furnace chamber to approximately 100 microns of mercury absolute.

A cooling coil 18a is mounted concentric about the upper portion of tube 12' and in spaced relation thereto. Coil 18a is positioned within a cylindrical jacket 19 and

passes through openings in the upper and lower side walls, respectively, of jacket 19 as shown in FIG. 1 of the drawings. A mixture of zinc dust and zinc powder bonded with sodium silicate is placed in jacket 19 and tamped between coils 18a to conduct heat away from the upper portion of tube 12'. The inlet of a heat exchanger coil 18b connects with coil 18a outside of the jacket 19. The coil 18b is spirally wound and passes adjacent the under surface of a collar 20 which is suitably constructed of grass or the like. A projecting member 20a on the under surface of collar 20 and integral therewith fits within the upper portion of jacket 19 between the inner wall of said jacket and the outer surface of tube 12'. Member 20a is pressed into a sealant 21 which is deposited within the jacket 19 on the upper surface of the zinc powder-zinc dust conducting material thereby completing a vacuum-tight seal. Water circulating within coils 18a—18b prevents reflected heat from the heating zone of the furnace from melting the sealant 21. As shown in FIG. 1 an O-ring seal 22 positioned in a recessed portion in the lower surface of plate 14 and the upper surface of collar 20 maintains a vacuum-tight seal.

As further shown in FIG. 1 of the drawings, a cylindrical graphite collar 23, positioned on the top wall 10a of the furnace 10, supports jacket 19. A recessed portion in the bottom surface of collar 23 fits within and extends to the lower surface of wall 10a. A refractory collar 24, concentric about the mid-portion of tube 12' and on a common vertical axis with collar 23, extends from the lower end of collar 23 to the heating zone of the furnace.

A heating coil 25 is provided intermediate of the refractory collar. Current passing through coil 25 furnishes the heat required to bring the apparatus to a desired temperature. The materials chosen for heating coil 25 depend upon the temperature gradient required in the furnace, i.e., Kanthal or Nichrome is satisfactory. The windings of coil 25 are separated by ceramic spacers 26 or the like, a coating of fire clay 27 or other insulating material covers the outer surface of the spacers 26. A thermocouple indicated diagrammatically at 28 passes through an aperture in the fire clay and into proximity to windings 25 in order to measure and control the temperature of the furnace. Extending from the lower portion of the heating zone of the furnace to the bottom wall 10b and in spaced relation around the lower portion of the tube 12' is a second refractory collar 29. A granular material 30 such as diatomaceous earth, or the like, insulates the heating elements of the furnace thereby maintaining a constant temperature within the device. In a preferred embodiment of the furnace, top and bottom walls, 10a—10b, respectively, are of asbestos cement, whereas side walls 10c are of stainless steel or the like and of approximately 0.040 inch thickness.

As indicated in the objectives, the present invention provides for the selective crystallographic orientation of crystal growth in a specimen—particularly a metal specimen. As will be described, the invention provides for preferential orientation of the crystallographic axes in both the vertical and horizontal planes of atoms.

Orientation with respect to a vertical plane is achieved by providing means whereby the specimen may be selectively rotated about a vertical axis with respect to the seed crystal and in addition orientation with respect to a horizontal plane of atoms is achieved by angularly positioning the seed crystal with respect to the specimen in a direction and at an angle measured from a desired and predetermined horizontal plane of atoms.

The mechanism for achieving said result comprises the crucible shown in FIGS. 2, 3, and 4A, 4B, respectively.

Crystal Crucible

The crucible assembly 11, diagrammatically illustrated in FIG. 1 of the drawings, is shown in greater detail in FIGS. 2 and 3.

FIGS. 2 and 3 of the drawings show a preferred embodiment of the complete crucible assembly diagrammatically illustrated in FIG. 1 of the drawings. Corresponding elements are designated by the same reference characters in FIGS. 1, 2, and 3. All elements illustrated in FIGS. 2 and 3 are machined of graphite except the cooling sleeve 33, which is preferably constructed of nickel-plated copper, and a pin 40 which is of Inconel metal.

The crucible, as is apparent from FIGS. 2 and 3, comprises a lower seed receptacle 32, an intermediate crucible housing 31, a segmented mold 35 and a riser 39.

The lower shouldered portion 31a of crucible housing 31 is machined to seat on the upper portion of seed receptacle 32. The seed receptacle is provided with a vertical seed receiving chamber 32b which traverses the length of receptacle 32. An extension 32a of the receptacle (FIG. 2) provides a contact surface for a cooling sleeve 33 which, as above noted, is made of heat conducting metal.

The interior of crucible housing 31 is machined to slidably receive the segmented mold 35. The mold may be internally machined to provide a casting matrix 35a of any desired geometric configuration. In the particular implementation shown in FIG. 2 a crystal of substantially disc-shaped configuration will be formed.

In order to secure the necessary crystallographic orientation as will be described, mold 35 is provided with a notch 37 which registers with a similar notch 37a in crucible housing 31. The notch 37a is positioned with respect to an indicia mark 38 inscribed on housing 31. The mold 35 is securely fixed in a position determined by the notches 37—37a by means of a key 36 as is clearly shown in FIG. 3.

Seed holder 32 is similarly provided with indicia marks 38a and 38b which are aligned with indicia mark 38. The mark 38b serves to initially position the seed with the seed receptacle. As will be described, each seed is provided with a reference mark, the position of which is obtained from X-ray diffraction patterns.

The riser 39 is applied over the mold 35 to complete the assembly and is fastened in place by a pin 52 which traverses a bore 41 provided in the housing 31 and riser 39, respectively.

In order to permit raising and lowering of the crucible assembly through the vertical furnace as will be described, the riser 39 is provided with a recess 42, a bore 53, and pin 40 to permit attachment of the operating cable 16 forming part of the furnace mechanism as shown in FIG. 1.

It will be noted from the assembled view of FIG. 3 that the orientation of the above-described elements of the crucible results in the upper end of seed receptacle 32 abutting the lower surface of mold 35 in a manner such that the seed receiving chamber 32b is continuous with the matrix 35a of the mold 35. The upper portion of the mold 35 in turn registers with a chamber 39a in the riser 39 to permit expansion of the specimen melt.

In a manner heretofore described in connection with FIG. 2 of the drawings, the mold 35 is fixedly positioned within the crucible housing 31. A charge of metal is placed within the casting matrix 35a of mold 35 and melted in any conventional manner to form a polycrystalline specimen having an external configuration corresponding to that of the matrix. A seed crystal of the desired axial orientation or as produced by the method and apparatus hereinafter to be discussed in connection with FIGS. 4A—4B, 5 and 6 of the drawings, respectively, is inserted within the seed receiving chamber 32b. The referred-to reference mark on the seed crystal is positioned with respect to mark 38b on surface 32c of receptacle 32: the upper surface of the seed is then ground even with surface 32c in a conventional manner thereby insuring that the seed crystal and surface 32c are in a horizontal plane. The seed receptacle 32 is then joined to the crucible 31 so that the ground surface of the seed crystal abuts the lower end of the specimen in the matrix

of the mold. To insure that the lower portion of the cast specimen within matrix 35a abuts the seed crystal within chamber 32b, a plug 34 (see FIG. 1) may be applied against the lower portion of the seed crystal within chamber 32b.

As previously described, the cooling sleeve 33 is positioned on extension 32a of the seed receptacle 32 to provide precise control of the temperature of different portions of the seed crystal within the seed receptacle.

The vacuum means described in connection with FIG. 1 of the drawings is then actuated to reduce the pressure within the furnace chamber to approximately 100 microns of mercury absolute. The complete assembly of FIG. 3 is then lowered to a position within the furnace (FIG. 1) where only the upper part of the seed is melted. The thermocouple 28 provides an accurate indication of the furnace temperature at such zone thereby enabling accurate control of the heating of the specimen and seed crystal.

The correct furnace temperature to permit just partial melting of the seed is obtained by trial and error or by surveying the furnace to obtain the correct temperature for a specified location of the assembly in the furnace. Seeds of undesirable axial orientation may be used in the determination of the correct furnace temperature, because, until this temperature is established for a fixed position of the assembly in the furnace, there is a possibility that the entire seed might be melted. This temperature can usually be established after a few trial runs. Once this temperature has been fixed, the same percentage of seed can be melted on each successive run, provided the assembly is placed in the same relative position in the furnace on each successive run.

It will be clear then that the specimen and the seed crystal with the exception of the portion surrounded by the cooling sleeve will be in a liquid phase. The lowering rate of the complete crucible assembly is then adjusted to permit all the heat of crystallization to be conducted away in the direction of the solidified portion of the seed. The solid/liquid interface is then maintained planar and horizontal. If lowering is too rapid, cooling may occur for the sides producing spurious crystal growth and a polycrystalline ingot. A rate of descent of the crucible assembly 11 of one-half inch per hour is preferred.

The present invention also provides means for modifying available seed crystals having a known horizontal axial orientation to a preferred, predetermined horizontal axial orientation. In other words, should it be desired to provide a seed crystal having a specific desired horizontal axial orientation for use in connection with the crucible assembly of FIGS. 2 and 3, a seed crystal having a horizontal axial orientation as close to the desired preferred horizontal axial orientation is selected and the special seed receptacle of FIG. 4A is employed to modify the horizontal axial orientation of the seed crystal to produce a seed crystal of the exact desired horizontal axial orientation.

The modified seed receptacle of FIG. 4A comprises a cylindrical yoke 43 and a replaceable seed receptacle 44. As illustrated, the longitudinal axis of the cavity 44a in which the seed crystal is to be positioned is canted with respect to the vertical longitudinal axis of the receptacle 44. The angle of the cavity axis may be drilled or otherwise provided at any angle with respect to the longitudinal axis of the receptacle to permit a change in the orientation of the selected seed crystal to that of the desired orientation. Preferably a maximum angle of about 5° has proven sufficient.

In the prior art methods a seed crystal of the exact orientation of the horizontal plane of atoms is required. Using the modified seed receptacle of FIG. 4A, a seed crystal of any approximate horizontal axial orientation may be used to prepare a seed crystal of exact preferred horizontal axial orientation. If the deviation of any

seed crystal is 5° or less from the horizontal axial orientation desired in a seed specimen as determined by X-ray diffraction studies, the longitudinal axis of cavity 44a of seed receptacle 44 is made to the specific angle (with respect to the longitudinal axis of the receptacle) required to complement the horizontal axial orientation of the seed crystal placed within the cavity 44a to produce a seed crystal of the exact desired horizontal axial orientation. For example, if a specimen is to be produced wherein the desired angle of the horizontal plane of atoms is 42°35' with respect to a horizontal reference plane of atoms and a seed crystal having this desired horizontal plane of atoms at an angle of 38°45' with respect to the same horizontal reference plane is available, the longitudinal axis of cavity 44a of the modified seed receptacle of FIG. 4A will be made at an angle of 3°50' with respect to the longitudinal axis of the receptacle 44. The modified seed receptacle of FIG. 4A may then be substituted for receptacle 32 of FIGS. 2 and 3 of the drawings. It will be clear that a number of receptacles 44 each having a different inclination of the angle of the cavity 44a is provided.

If the angular deviation between the selected seed crystal and the preferred orientation of the horizontal plane of atoms desired in the seed crystal to be produced exceeds 5°, however, then it is necessary to employ the additional seed mold 45 of FIG. 4B in conjunction with the modified receptacle of FIG. 4A to produce an intermediate seed crystal having the desired horizontal plane of atoms.

The outer wall of cylindrical mold 45 is inserted within an annular recessed portion 46 of the modified seed receptacle of FIG. 4A, the top surface 44b of receptacle 44 abuts the lower surface 45b of mold 45. The orientation of the horizontal plane of atoms of the selected seed crystal is determined by conventional X-ray diffraction methods. The angular difference between the measured orientation of the selected seed crystal and the preferred orientation to be produced within the newly-formed crystal is then calculated, and divided into any suitable number of increments such that the angle for any single increment does not exceed 5° (the maximum angular inclination in view of the diameter of receptacle 44). The axis of cavity 44a in which the selected seed crystal is inserted is then made, as by drilling, at an angle with respect to the longitudinal axis of receptacle 44 corresponding to such increment. In another modification of the apparatus utilized in this incremental method of changing the axial orientation of a seed crystal, a number of replaceable receptacles each containing a cavity which varies from the preceding receptacle cavity by a small increment may be provided. Selection of a single receptacle or any combination of receptacles having the desired inclinations, therefore, will produce a seed crystal of desired orientation in the manner heretofore described.

In utilizing the seed crystal apparatus of FIGS. 4A-4B of the drawings, a charge of metal is placed into cavity 45b of the mold 45 and melted to form a polycrystalline ingot. The selected seed crystal of the same metal as that placed into cavity 45b, is then inserted within cavity 44a of the modified seed receptacle of FIG. 4A, the top of the seed crystal is ground so that its surface is in the same plane as the bottom surface 45b of seed mold 45. The cylindrical seed mold 45 and modified seed receptacle 44 are then joined together and lowered into the furnace of FIG. 1 so that the entire charge, with the exception of a small portion of the seed crystal, becomes molten. Upon cooling, the angle of the horizontal plane of atoms within the newly-formed seed crystal within mold 45 will vary from the orientation of the selected seed crystal by an angle equal to the angle of the axis of chamber 44a with respect to the longitudinal axis of receptacle 44. As the last step in the incremental method of changing the axial orientation of a seed crystal, or, as previously described in connection with changes of 5° or less, a

seed receptacle having a cavity of the exact inclination may be drilled or a replaceable receptacle having the desired angle of inclination may be selected. A reference mark is scribed on the upper surface of the seed crystal to position the seed crystal with respect to mark 38c on surface 44b of receptacle 44 during each step of this reorienting procedure.

There is shown in FIGS. 5 and 6 a preferred embodiment of the aligning fixture whereby a preferred vertical plane of atoms may be obtained. Corresponding elements are designated by the same reference characters in FIGS. 2, 3, 5, and 6. Preliminary to mounting the crucible assembly in the furnace, the segmented mold 35 is inserted within housing 31 in the manner previously described in connection with FIGS. 2 and 3 of the drawings. The longitudinal axis or parting plane of mold 35 is then aligned with reference mark 38. The housing 31 is slidably inserted within the cavity of an alignment fixture 47. Fixture 47 is preferably of hollow cylindrical form and constructed of brass or the like. An alignment window 48 in the center of a cut-out portion 49 permits alignment of the reference mark 38 on the crucible 31 inserted within alignment fixture 47 with mark 38d scribed on fixture 47, as best seen in FIG. 6 of the drawings. Angular divisions 50 are scribed on the lower peripheral edge of fixture 47 using the reference mark 38e as an index.

As shown in the cut-away portion of FIG. 6 of the drawings, seed receptacle 32 fits within a stepped yoke 51, preferably constructed of brass or the like. The upper surface 51a of yoke 51 abuts the lower surface of the aligning fixture 47 when the housing 31 and seed receptacle 32 are attached. The reference mark 38 on housing 31 aligns with the marks 38a, 38d, and 38e on the seed receptacle 32, alignment fixture 47 and stepped yoke 51, respectively, as best seen in FIG. 6. As aforementioned, the axis or parting plane of mold 35 is aligned with reference mark 38. The bottom portion of the extension 32a extends slightly below the lower surface 51b of yoke 51 as shown in FIG. 6 of the drawings.

By means of Laue back-reflection patterns such as are well known in the art, the vertical planes of atoms within a particular seed crystal are determined, and an alignment mark is scribed on the seed crystal corresponding to a reference vertical plane of atoms. At the same time a corresponding mark is placed on the back-reflection pattern. The angle that a desired vertical plane of atoms makes with respect to the reference vertical plane of atoms is then determined by aligning said reflection pattern (which is an X-ray photograph) with the index mark on a conventional Geringer chart (see "Structure of Metals," 2d ed. by C. S. Barrett).

With reference marks aligned on members 31, 35, 32, 47, and 51, respectively, as best seen in FIG. 6 of the drawings, the yoke 51 is rotated in a direction and at an angle equal to the difference between the reference vertical plane of atoms and the desired, predetermined vertical plane of the atoms as shown on the back reflection pattern. The angular deviation is measured by aligning the reference mark 38e scribed on yoke 51 with the computed deviation as measured by angular divisions 50 on the lower peripheral edge of fixture 47. The vertical axis or parting plane of the mold 35 and the crystal to be formed therein now corresponds to the desired, predetermined vertical plane of atoms.

The alignment fixture 47 and yoke 51 are then removed from the housing 31 and seed receptacle 32, respectively. The riser 39 and cooling sleeve 33 are attached in the manner heretofore described in connection with FIG. 2 of the drawings and the apparatus is ready for lowering into the furnace.

As a specific example of the process of this invention, large monocrystals of aluminum of desired external form in which the crystallographic axes are oriented in any

desired manner with respect to the external form have been produced utilizing the apparatus of FIGS. 1, 2, and 5, respectively.

As described in connection with FIG. 1 of the drawings, the composition of furnace chamber 12' depends upon the melting point of the crystal to be prepared. Preferably, a fused quartz tube may be used in the preparation of aluminum crystals.

In order to control the direction of the crystallographic axes, molds of the type illustrated in the upper part of FIG. 2 are utilized. A charge of aluminum metal (M.P. 660° C.) is precast by conventional centrifugal casting methods to conform to the configuration of matrix 35a of mold 35, the bottom portion of said casting is then ground smooth in a conventional manner.

A seed crystal of the desired axial orientation or as produced in the apparatus of FIGS. 4 and 6, respectively, is placed into the cavity 32b of the seed receptacle 32 or the cavity 44a of the modified seed receptacle 44. A vacuum is maintained within the furnace 10 of FIG. 1 for approximately 90 minutes after the heat within the furnace is shut off to prevent oxidation of the graphite.

Large, single crystals of copper have also been produced utilizing the steps heretofore described for the production of single crystals of aluminum. A mullite tube 12' was substituted for the fused quartz tube heretofore described in the preparation of monocrystals of aluminum, however.

Metallic monocrystals of the face centered cubic system of metals may be suitably produced utilizing the apparatus of FIGS. 1, 2, 4A, 4B, and 5, respectively. It is to be understood, of course, that the melting point of the metal from which the monocrystalline specimens are to be produced determines the composition of tubes 12' to be utilized in the furnace of FIG. 1 of the drawings.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of invention as defined in the appended claims.

What is claimed is:

1. The method of growing monocrystals of a desired crystallographic orientation comprising the steps of: selecting a seed crystal having atoms arranged in a selected vertical plane and a selected plane positioned β degrees with respect to a reference horizontal plane, molding a crystalline specimen of the same composition as said seed crystal into a predetermined external configuration having a vertical reference plane, said crystalline specimen having said vertical reference plane positioned γ degrees with respect to said reference horizontal plane, placing a surface of said seed crystal corresponding to its selected plane into contact with said crystalline specimen at an angle substantially equal to $|\beta - \gamma|$ degrees with respect to said reference horizontal plane, positioning the vertical plane of said seed crystal so that it coincides with the selected vertical reference plane of said crystalline specimen, melting said crystalline specimen and a portion of said seed crystal and allowing the molten specimen crystal and the molten portion of said seed crystal to crystallize.

2. The method in claim 1 wherein $|\beta - \gamma|$ is substantially equal to or less than 5.

3. The method of growing monocrystals of aluminum of a desired crystallographic orientation comprising the steps of: selecting an aluminum seed crystal having atoms arranged in a selected vertical plane and a selected plane positioned β degrees with respect to a reference horizontal plane, molding an aluminum crystalline specimen into a predetermined external configuration having a vertical reference plane, said crystalline specimen having said vertical reference plane positioned γ degrees with respect to said reference horizontal plane, placing a surface of said seed crystal corresponding to its selected plane

9

into contact with said crystalline specimen at an angle substantially equal to $|\beta-\gamma|$ degrees with respect to said reference horizontal plane, positioning the selected vertical plane of said seed crystal so that it coincides with the vertical reference plane of said crystalline specimen, heating said crystalline specimen and a portion of said seed crystal in contact with said crystalline specimen to above 660° C., and slowly cooling the molten crystalline specimen and the molten portion of said seed crystal and maintaining the pressure at approximately 100 microns of mercury until said specimen crystallines.

10

References Cited in the file of this patent

UNITED STATES PATENTS

1,793,672	Bridgman	Feb. 24, 1931
2,842,468	Brenner	July 8, 1958
2,862,797	McKay	Dec. 2, 1958
2,889,240	Rosi	June 2, 1958
2,893,847	Schweickert et al.	July 7, 1959
2,907,715	Cornelison	Oct. 6, 1959

OTHER REFERENCES

Karstensen: Journal of Electronics and Control, vol. 3, July-December 1957, pp. 305-307.