

April 21, 1964

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DENDRITIC SEED CRYSTALS HAVING A CRITICAL SPACING
BETWEEN THREE INTERIOR TWIN PLANES
Filed Dec. 30, 1960

3,130,040

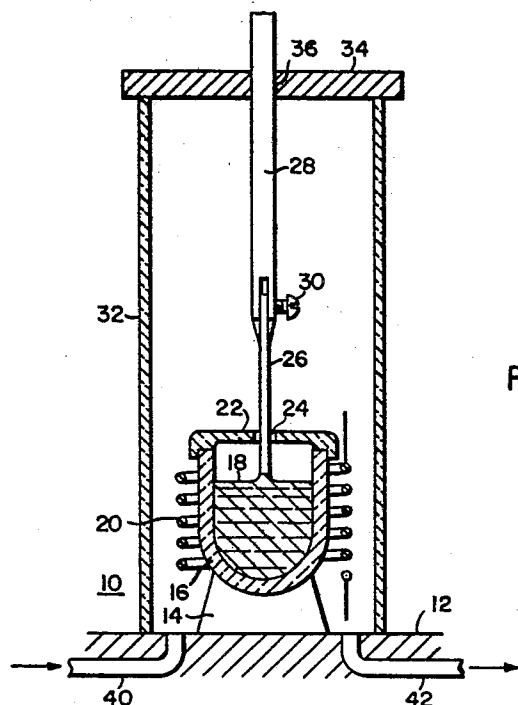


Fig. 1.

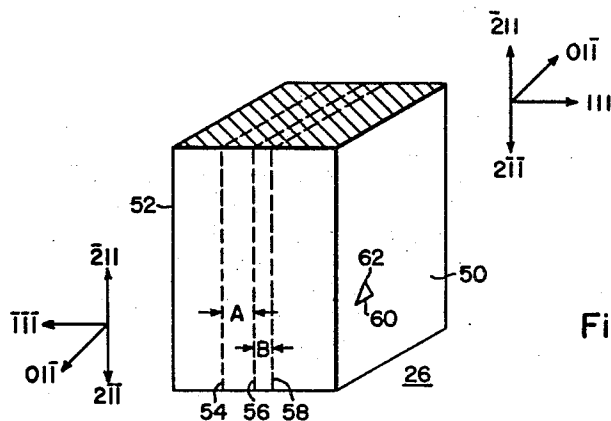


Fig. 2.

WITNESSES

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3,130,040

DENDRITIC SEED CRYSTALS HAVING A CRITICAL SPACING BETWEEN THREE INTERIOR TWIN PLANES

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Filed Dec. 30, 1960, Ser. No. 79,680

6 Claims. (Cl. 75—5)

This invention relates to the process of producing crystals of solid materials and, in particular, to dendritic semiconductor crystals.

This application is a continuation in part of U.S. patent application Serial No. 16,384, now abandoned, filed March 21, 1960, the assignee of which is the same as that of the present application.

At the present time crystals of many solid materials are produced by preparing a melt of the solid material, contacting the surface of the melt with a previously prepared crystal of the material and slowly withdrawing the previously prepared crystal, usually at the rate of the order of an inch an hour, whereby to produce a desired grown crystal member. It has been the invariable practice in this process to maintain the melt during the crystal-growing process at a temperature slightly above the melting point of the solid material.

The nature and configuration of the withdrawn crystals produced by such prior art practices have generally been uncontrollable except within relatively broad limits. Thus, the thickness has not been readily maintained within precise dimensions. In many cases, surface and internal imperfections such as dislocations and other crystal structure flaws have been present in the grown crystals.

In the semiconductor industry, crystals of silicon, germanium and compounds of the group III-group V elements have been grown from melts in accordance with this prior art practice. In order to employ such grown crystals in semiconductor devices, it has been necessary to saw them into slices using, for example, diamond saws. Thereafter, dice of desired shape have been cut from these slices. The sawed surfaces of the dice have been lapped or otherwise mechanically polished to remove disturbed or otherwise unsatisfactory surface layers, which treatment is followed by an etch to remove microscopic surface imperfections. As a result of this working, which is performed on expensive precision machinery and requires highly-skilled labor, there may be a loss of as much as 90 percent of the original grown crystal in securing dice that have useful semiconductor shape and configuration.

An object of the present invention is to provide a process for growing dendritic crystals of a semiconductor material having a precisely controllable thickness and a predetermined internal twin plane structure by seeding a supercooled melt of the semiconductor material with a seed crystal having a predetermined and preselected internal twin plane structure which is carried over into the grown dendrite.

Another object of the present invention is to provide seed crystals to enable the drawing of flat dendritic crystals of a semiconductor material which crystallizes in the diamond cubic lattice structure from a melt of the material which seed crystals have three twin planes extending therethrough, one twin plane being spaced from 0.1 to 5 microns, from a central twin plane and a second twin being spaced from 0.1 to 30 microns from the central twin plane, the spacing and configuration of the twin planes being carried over into the dendrite from the seed crystal.

Other objects of the present invention will, in part, be obvious and will, in part, appear hereinafter.

For a better understanding of the nature and objects of

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the invention, reference should be had to the following detailed description and drawings, in which:

FIG. 1 is a view in elevation, partly in cross section, of a crystal growing apparatus used in accordance with the teachings of this invention; and

FIG. 2 is a greatly enlarged fragmentary view of a dendritic crystal having three twin planes.

In accordance with the present invention it has been discovered that the use of seed crystals having three internal twin planes spaced a predetermined distance apart and extending to the edges of the seed will enable flat dendritic crystals to be pulled from a supercooled melt of a solid material corresponding to the seed crystal. The seed crystal structure is critical in successfully initiating the growth of dendritic crystals having a uniform thickness and parallel flat faces. These flat dendritic crystals may be pulled or grown from melts of the material at a relatively high rate of speed of pulling of the order of 100 times and greater than the linear pulling velocity previously employed in the art. The thickness of the crystals may be readily controlled and surface imperfections minimized or reduced by following the teachings embodied in U.S. application, Serial No. 844,288, now Patent No. 3,031,403, filed October 5, 1959, and assigned to the assignee of the present invention.

More particularly, in practicing the process, a melt of the material to be grown into a flat dendritic crystal is prepared at a temperature slightly above the melting temperature thereof. The surface of the melt is contacted with at least a tip of a previously prepared seed crystal having three internal twin planes disposed a preselected distance apart at the interior thereof, the three internal twin planes extend entirely across that tip of the seed which contacts the melt, as will be detailed hereinafter, the seed crystal being oriented with a $\langle 211 \rangle$ direction vertical to the melt surface. Other necessary or desirable crystallographic and physical features of the seed crystal will be pointed out in detail hereinafter. The seed crystal is dipped into the surface of the melt a sufficient period of time to cause wetting of the lower surface of the seed, usually a period of time a few seconds to a minute is adequate, and, then, the melt is supercooled rapidly following which the seed crystal is withdrawn with respect to the melt at a speed of the order of from one to ten inches a minute. Under some conditions, considerably slower pulling speeds than an inch per minute can be employed, for example 0.2 inch per minute. Pulling speeds of from 4 to 8 inches per minute have given particularly good results, though greater speeds of up to 25 inches per minute may be employed. The degree of supercooling and the rate of pulling can be readily so correlated that the seed crystal withdrawn from the melt comprises solidified melt material thereon of a precisely desired thickness, having the desired crystallographic orientation and having the internal twin plane structure of the seed crystal continued therethrough. A detailed description of the preferred seed crystal structure will be set forth hereinafter.

The present invention is particularly applicable to solid materials crystallizing in the diamond cubic lattice structure. Examples of such materials are the elements silicon and germanium. Likewise, stoichiometric compounds having an average of four valence electrons per atom respond satisfactorily to the crystal growing process. Such compounds which have been processed with excellent results comprise substantially equal molar proportions of an element from group III of the periodic table, and particularly aluminum, gallium and indium, combined with an element from group V of the periodic table, and particularly phosphorus, arsenic and antimony. Compounds comprising stoichiometric proportions of group II and group VI elements, for example, ZnSe and ZnS, can be processed. These materials crystallizing in the dia-

mond cubic lattice structure are particularly satisfactory for various semiconductor applications. Furthermore, the diamond cubic lattice structure materials may be intrinsic or they may be doped with one or more impurities to produce n-type or p-type semiconductor materials. The crystal growing process of the present invention may be applied to all of these different materials.

For a better understanding of the practice of the invention, reference should be had to FIG. 1 of the drawings wherein there is illustrated apparatus 10 for practicing the process. The apparatus comprises a base 12 carrying a support 14 for a crucible 16 of a suitable refractory material such as graphite to hold a melt of the material from which flat dendritic crystals having predetermined crystal orientation and internal twin plane structure are to be drawn. Molten material 18, for example, germanium, is maintained within the crucible 16 in the molten state by a suitable heating means such, for example, as an induction heating coil 20 disposed about the crucible. Controls, not shown, are employed to supply an alternating electrical current to the induction coil 20 to maintain a closely controllable temperature in the body of the melt 18. The temperature should be readily controllable to provide a temperature in the melt a few degrees above the melting point and also to reduce heat input so that the temperature drops in a few seconds, for example in 5 to 10 seconds to a temperature at least one degree below the melting temperature and preferably to supercool the melt from 5 to 15° C., or lower. A cover 22 closely fitting the top of the crucible 16 may be provided in order to maintain a low thermal gradient above the top of the melt. Passing through an aperture 24 in the cover 22 is a preferred seed crystal 26, having three internal twin planes spaced a predetermined distance apart such that one twin is from 0.1 to 5 microns, and preferably from .25 to 4 microns, from the central twin, and the other twin is disposed on the other side of the central twin and spaced from 0.1 to 30 microns, and preferably from 0.25 to 15 microns, therefrom. The seed is oriented crystallographically as will be disclosed in detail hereinafter. The crystal 26 is fastened to a pulling rod 28 by means of a screw 30 or the like. The pulling rod 28 is actuated by suitable mechanism to control its upward movement at a desired uniform rate, ordinarily in excess of one inch per minute. A protective enclosure 32 of glass or other suitable material is disposed about the crucible with a cover 34 closing the top thereof except for an aperture 36 through which the pulling rod 28 passes.

Within the interior of enclosure 32 is provided a suitable protective atmosphere entering through a conduit 40 and, if necessary, a vent 42 may be provided for circulating a current of such protective atmosphere. Depending on the crystal material being processed in the apparatus, the protective atmosphere may comprise a noble gas such as helium or argon, or a reducing gas such as hydrogen or mixtures of hydrogen and nitrogen, or nitrogen or the like or mixtures of two or more gases. In some cases, the space around the crucible may be evacuated to a high vacuum in order to produce crystals of materials free from any gases.

In the event that the process is applied to compounds having one component with a high vapor pressure at the temperature of the melt, a separately heated vessel containing the component may be disposed in the enclosure 32 to maintain therein a vapor of such compound at a partial pressure sufficient to prevent impoverishing the melt or the grown crystals with respect to the component. Thus an atmosphere of arsenic may be provided when crystals of gallium arsenide are being pulled. The enclosure 32 may be suitably heated, for example, by an electrically heated cover, to maintain the walls thereof at a temperature above the temperature of the separately heated vessel containing the arsenic in order to prevent condensation of arsenic thereon.

Referring to FIG. 2 of the drawing, there is illustrated, in greatly enlarged view, a section of a seed crystal 26 having three internal twin planes. Similar seed crystals may be obtained in various ways, for example, by supercooling a melt of the solid semiconductor material to a temperature at which a portion thereof solidifies at which time some dendritic crystals having three internal twin planes with a preferred spacing will be formed and may be removed from the melt. While these crystals may not be uniform, on the surfaces as shown in FIG. 2, they are suitable for seed purposes. Also one can cut from a large crystal a section suitable for use as a seed crystal. However, seed crystals are available from previously grown dendrites and such seeds will be normally used in practicing the process. The seed crystal of FIG. 2 is a portion of a previously grown dendrite which is to be used as a seed.

The seed crystal 26 comprises two relatively flat parallel faces 50 and 52 with three intermediate interior twin planes 54, 56 and 58 extending therethrough. Examination will show that the crystallographic structure of the preferred seed on both faces 50 and 52 is that indicated by the crystallographic direction arrows at the right and left faces, respectively, of the figure. It will be noted that the horizontal directions perpendicular to the flat faces 50 and 52 and parallel to the melt surfaces are $\langle 111 \rangle$. The direction of growth of the dendritic crystal will be in a $\langle 211 \rangle$ crystallographic direction. If the faces 50 and 52 of the dendritic crystal 26 were to be etched preferentially to the $\{111\}$ planes with a silver nitrate-nitric acid etch, most other nitric acid etches or a potassium ferricyanide etch, they will both exhibit equilateral triangular etch pits 60 whose vertices 62 will point upwardly while their bases will be parallel to the surface of the melt. If the faces 50 and 52 are etched with a superoxol etch or a hydrogen peroxide etch, somewhat rounded pits having a roughly triangular shape are formed. However, while the vertices will point downwardly and the bases are essentially parallel to the melt surface, these are not the sharply pointed triangular etch pits referred to herein as suitable for determining the seed directions. It is an important feature of the preferred embodiment of the present invention that the etch pits on both faces 50 and 52 of seed crystal 26, formed by etching with a silver nitrate-nitric acid etch, a suitable nitric acid etch or a potassium ferricyanide etch have their vertices 60 pointing upwardly. A non-twinned crystal or a crystal containing two twin planes or any even number thereof will exhibit triangular etch pits on one face whose vertices will be pointing opposite to the direction of the vertices on the other face assuming of course that both faces are etched with an etchant from the same class.

The spacing or lamellae between the successive adjacent twin planes 54, 56 and 58 ordinarily is not uniform in the best seed crystals. The lamellar spacing, such as "A" between the twin planes 54 and 56, and "B" between twin planes 56 and 58, is of the order of microns; that is from less than one micron to approximately 30 microns. A good seed crystal should contain three internal twin planes, the lamella between one set of two adjacent twin planes should be thin enough to prevent wrong-direction growth, but not so narrow as to interfere with initial seeding by terminating too readily. A suitable lamella is one having a width of from 0.1 micron to 5 microns and preferably from 0.25 micron to 4 microns. The lamella between the other set of adjacent twin planes (the center twin plane 56 being common to both sets) should not be so wide as to interfere with growth, or to be unusually receptive to grain boundary degeneration, a suitable lamella is one having a width of from 0.1 micron to 30 microns and preferably from 0.25 micron to 15 microns. The best seed crystal is one having three twin planes which are separated by lamellae of about 1.7 and about 5 microns respectively. Generally, it is not

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desirable to employ a seed having an equal lamellar spacing between twins, but seeds having equal lamellar spacings of less than 5 microns may be used satisfactorily.

If a seed crystal having an unsuitable three twin configuration, particularly with spacing outside the ranges given, is introduced into the melt in the manner previously described a plurality of dendrites may grow in an uncontrollable fashion and in several or all of the allowed crystallographic directions. Some of such dendrites would lose one twin plane. If a dendrite is grown from a seed in which the narrow twin spacing exceeds 5 microns, one of the (111) faces will have a central stripe of dislocations and will not be suitable for device fabrication.

Some satisfactory dendrites have been grown from seed crystals having an even number of twin planes, however, since no even numbered twin configuration can show a preference for a single direction of growth, some undesirable side growth frequently results when such seeds are employed. No such problems occur with the three twin plane configuration seeds of the present invention.

A dendrite, when properly seeded with a seed having three twins separated by lamellae of the preferred width preserves the twin planes and their spacing as in the seed throughout its own subsequent growth, barring an accident. This spacing is not appreciably altered by growth or thermal conditions.

In all cases, all the twin planes in a good seed crystal extend entirely through the seed. When one or more of the twin planes terminate within the seed, and do not extend to the edges, the seed behaves as if no such twin plane is present at all insofar as pulling dendrites from the melt is concerned. If two of the three twin planes in a dendrite containing three twin planes are completely enclosed within a crystal, then satisfactory dendrites will not grow. If the crystal is cut, melted back, fractured, or otherwise treated to expose all three twin planes at at least one edge or one surface contacting the melt, then satisfactory dendrites can be pulled therewith.

It has been discovered that, due to the microscopically small lamellar distances between twin planes, particularly in the preferred three twin seeds, it is highly difficult to determine whether one or more than one twin plane is present in a dendrite or seed crystal. One technique for determining the number of twin planes present in a dendrite comprises scribing a line transverse of the length of the dendrite, bending the dendrite at the scribed line to bow it away from the scribed line until it fractures thereat, and, without polishing or otherwise working on the fractured face, examining it under a microscope at a magnification of at least 100 $\times$, and preferably 200 $\times$ to 500 $\times$. The fracturing results in relatively flat faces developing at successive lamellae at different angles to each other which stand out distinctly under illumination. Also, preferentially etching of a polished cross section, preferably cross sections lapped at an angle to the flat face, so as to selectively distinguish the lamellae from each other, will enable the separate twin planes to be clearly distinguished.

The direction of withdrawal of the seed crystal 26 having three twin planes from the melt 18 must be with the direction of the vertices 58 of the etch pits being upward and the bases being substantially parallel to the surface of the melt. This statement of course applies to etch pits formed employing a silver nitrate-nitric acid etch, a nitric acid etch or a potassium ferricyanide etch. If the seed crystal is not from a dendrite, and does not have a flat (111) surface, then the direction of its crystal axes should be determined at the twin plane faces where the proper $\langle 211 \rangle$ orientation may be established. When so withdrawn, the melt will solidify at the bottom of the crystal in a satisfactory prolongation thereof. Reference should be had to U.S. patent application, Serial No.

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14,396, now Patent No. 3,093,520, filed March 11, 1960, the assignee of which is the same as that of the present case, for a detailed explanation of the dendritic growth process. If the crystal 26 were to be inserted into the melt so that the vertices 58 pointed downwardly, very erratic grown crystals will be produced which are not only of non-uniform dimensions but grow at angles of 120° to the seed and produce very irregular splines, and generally are unsatisfactory.

When a relatively cold flat seed crystal has been introduced into the melt which is at a temperature of only a few degrees above the melting point of the material, the melt will dissolve the tip of the seed crystal. However, there will be a meniscus-like contact between the seed crystal and the body of the melt. Such contact should be maintained by keeping the temperature of the melt close to the melting point of the material.

Upon reducing the power input to the heating coil in order to supercool the melt (or reducing the applied heat if other modes of heat application than inductive heating are employed) there will be observed in a period of time of the order of 5 seconds after the heat input is reduced to a crucible of about 2 inches in diameter and length of 2 inches, the supercooling being about 8° C., an initial elongated hexagonal growth or enlargement on the surface of the melt at the tip of the seed crystal. The hexagonal surface growth increases in area so that in approximately 10 seconds after heat input is reduced its area is approximately 3 times that of the cross section of the seed crystal. At this stage, there will be evident spikes growing out of the two opposite hexagonal vertices lying in the plane of the seed. These spikes appear to grow at the rate of approximately two millimeters per second. When the spikes are from two to three millimeters in length the seed crystal pulling mechanism is energized to pull the crystal from the melt at the desired rates. The initiation of pulling is timed to the appearance and growth of the spikes for best results.

After pulling the seed crystal upwardly from the supercooled melt, it will be observed that the flat solid diamond-shaped area portion is attached to the seed crystal and that a downwardly extending dendritic crystal has formed at each end of the elongated diamond area adjacent the spike. Accordingly, two dendritic crystals can be readily pulled from the melt at one time from a single seed crystal. By continued pulling the two dendritic crystals may be extended to any desired length.

If the seed crystal is disposed so that one edge is nearer the thermal center of the melt crucible than is the other edge, it is possible to increase briefly either the pulling rate or the temperature of the melt, and under these variations the dendritic crystal furthest away from the thermal center or in a hotter region will usually stop growing and thereafter only a single dendritic crystal will be attached to and grow from the seed. Also, if the double dendritic crystal attached to the original seed crystal is introduced into the same or another melt slightly above the melting temperature and after supercooling the melt, on pulling the double dendritic crystal from the surface, there will be formed two diamond-shaped areas attached to the double dendrites and four dendritic crystals will be pulled, two attached to each of the original dendrites. Thus, in one instance four germanium dendrites each 5 inches in length were pulled from the melt. While more than 4 dendritic crystals can be pulled from a melt, there may arise interference and other factors which will render such growth difficult.

If the seed crystal 26 were to be pulled at a slowly increasing rate just as supercooling of the crucible is being effected by reducing the heat input, so that at the end of about 5 to 10 seconds the full pulling rate is being applied, then only one dendritic crystal will usually be attached to the seed crystal.

The seed crystal need not be flat. It may be of any suitable size or shape as long as its crystal orientation

and twin plane configuration corresponds to that shown in FIG. 2. Usually a portion of a previously grown dendritic crystal having the desired twin plane configuration will be quite satisfactory for use as a seed and ordinarily a portion of such a dendrite will be used as the seed crystal. The pulled dendritic crystal need have no direct relation to the seed crystal as far as size is concerned. The pulled dendritic crystal will have a size and shape depending on the pulling conditions.

In growing satisfactory flat faced dendritic crystals in accordance with the present invention, the melts of the materials may be supercooled as much as 30 to 40° C. below their melting point. In practice, however, supercooling of from 5 to 15° C. has given best results with germanium and indium antimonide, for example. A greater degree of supercooling requires higher rates of crystal withdrawal from the melt as well as requiring more precise control of the speed of pulling. Germanium and indium antimonide dendritic crystals have been satisfactorily pulled at rates of from 4 inches to 12 inches per minute from melts supercooled 5° C. to 15° C. As an example, these crystals have had a highly uniform thickness selected from the range of from 3 to 20 mils and a selected width of from 1 to 4 millimeters. The length of these crystals is limited solely by the pulling apparatus employed. No difficulty has been experienced in pulling crystals of, for example, 300 feet in length in a slightly modified crystal pulling furnace as normally used in the art.

Generally, the pulled dendritic crystals will have a thickness of the order of from 1 to 25 mils and the width across the flat faces may be from 20 mils to 200 mils and even wider. The surface at the flat faces will exhibit essentially perfect (111) orientation. The grown dendritic crystals of this invention will be essentially twinned crystals which are not of single crystal structure. Properly grown crystals will have faces that comprise flat areas on either side which are parallel and planar within a wavelength, of sodium light, per centimeter of length.

While the dendritic crystals will exhibit some degree of edge serration, dendritic crystals have been obtained with fairly uniform edges having a minimum of ragged appearance. The serrated edges comprise only a small portion of the crystals and can be readily removed or left intact in dice since they do not affect the properties of the central or main body portion of the dendrites.

The flat dendritic crystals of the present invention are relatively flexible, and crystals of a thickness of 7 mils may be bent on a radius of the order of 4 inches or even less without breaking. Consequently, crystals may be continuously drawn from the melt and wound on a cylinder of a radius of this order in continuous lengths, as desired. The thinner crystals obviously can be wound to a smaller radius than crystals of greater thickness.

The grown dendritic crystals of the present invention have surfaces of such perfection that, in the case of semiconductor materials they may be employed for semiconductor applications simply by applying to the faces thereof desired alloys or solders without any intermediate polishing, lapping or etching. In fact, in general, etching results in a degradation of the perfection of the crystal face. In all cases the crystal surfaces have a perfect (111) orientation as grown. For making such devices as diodes, transistors, photodiodes and other similar semiconductor devices, the (111) surfaces are a particularly desired orientation.

A further advantage of the present invention is that dice for semiconductor and other applications may be prepared from the grown dendritic crystals by a very simple operation which does not require the use of sawing, ultrasonic cavitation, or other involved cutting processes. To prepare a desired convex polygonal shape from a flat dendritic crystal, it is only necessary to score the surface lightly with a diamond, for example, and upon a slight flexing,

the dendrite will break along the score mark, thereby leaving the desired shape die.

The following examples are illustrative of the present invention.

Example I

In apparatus similar to FIG. 1, a graphite crucible containing a quantity of germanium is heated by the induction coil to a temperature several degrees above the melting point of germanium, the temperature being about 938° C., until the entire quantity forms a molten pool. A dendritic seed crystal having three interior twin planes spaced 5 microns and 1.7 microns apart respectively extending entirely therethrough and oriented as in FIG. 2 of the drawing, held vertically in a holder is lowered until its lower end touches the surface of the molten germanium. The contact with the molten germanium is maintained until a small portion of the end of the dendritic seed crystal has melted. Thereafter the temperature of the melt is lowered rapidly in a matter of 5 seconds by reducing current to the coil 20, to a temperature 8° below the melting point of the germanium so that the melt is supercooled (about 928° C.). After an interval of approximately 10 seconds at this temperature the germanium seed crystal is pulled upwardly at a rate of 7 inches per minute. Two dendritic crystals were attached to the seed and each was of a thickness of 7 mils and was approximately 2 mm. in width. The grown dendritic crystals had substantially flat and highly parallel faces from end to end with (111) orientation. The germanium dendritic crystals so grown were found to have no surface imperfections except for a number of microscopic steps differing by about 50 angstroms and were of a quality suitable for semiconductor applications. The resultant dendrite, thus grown, had three twin planes extending throughout its length which were spaced 5 microns and 1.7 microns apart respectively.

In a similar manner dendrites were pulled successfully using seeds having three twin planes wherein the lamellar spacing between twin successive planes was in the range of from 0.1 to 4 microns, for one and from 0.1 to 15 for the other. The dendrites, thus grown, all had three twin planes extending throughout the length of the dendrite.

Example II

The procedure of Example I was repeated except that the seed employed had three interior twin planes spaced 30 microns and 1.7 microns apart respectively extending entirely through the seed.

The resulting dendrite was found to have some grain boundary degeneration along the edges. A section of this dendrite could not be used as a seed until the degenerate regions were removed. This illustrates the fact that the 30 micron spacing is at about the limit for the spacing between twin planes.

While the above description emphasizes the application of the present invention to semiconductor materials, it will be understood that it may be employed for producing grown dendritic crystals from any metal or alloy or compound of zinc blends structure and growable from a melt. By the practice of the present invention flat crystals of high perfection of orientation may be produced by the practice of the process disclosed herein. No known present day technique or apparatus is capable of duplicating the precision of the orientation of pulled crystals disclosed herein.

It will be understood the above description and drawing are only illustrative and not limiting.

We claim as our invention:

1. A dendritic seed crystal of a material crystallizing in the diamond cubic lattice structure having three interior twin planes extending entirely therethrough, said interior twin planes being spaced from 0.1 to 5 microns and from 0.1 to 30 microns apart, respectively.
2. A dendritic seed crystal of a material crystallizing in the diamond cubic lattice structure having three in-

terior twin planes extending entirely therethrough, said interior twin planes being parallel to each other and being spaced from 0.5 to 4 microns and from 0.5 to 15 microns apart, respectively.

3. A dendritic seed crystal of a material crystallizing in the diamond cubic lattice structure having two relatively flat parallel faces, and with three interior twin planes extending entirely therethrough, said interior twin planes being parallel to the relatively flat parallel faces and said interior twin planes being spaced 5 microns and 1.7 microns apart, respectively.

4. A dendritic crystal of a semiconductor material crystallizing in the diamond cubic lattice structure having two relatively flat parallel faces comprised of {111} planes, and having three interior twin planes extending entirely therethrough relatively parallel to the parallel faces, said twin planes being spaced from 0.1 to 5 microns and 0.1 to 30 microns apart, respectively.

5. A dendritic crystal of a semiconductor material crystallizing in the diamond cubic lattice structure having two relatively flat parallel faces comprised of {111} planes, and having three interior twin planes extending entirely therethrough relatively parallel to the parallel faces, said twin planes being spaced from 0.5 to 4 microns and 0.5 to 15 microns apart, respectively.

6. A dendritic crystal of a semiconductor material crystallizing in the diamond cubic lattice structure having two relatively flat parallel faces comprised of {111} planes and having three interior twin planes extending entirely therethrough relatively parallel to the parallel faces, said twin planes being spaced 5 microns and 1.7 microns apart, respectively.

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