METHOD AND APPARATUS FOR GROWING SEMICONDUCTOR CRYSTALS

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Fig. 1.

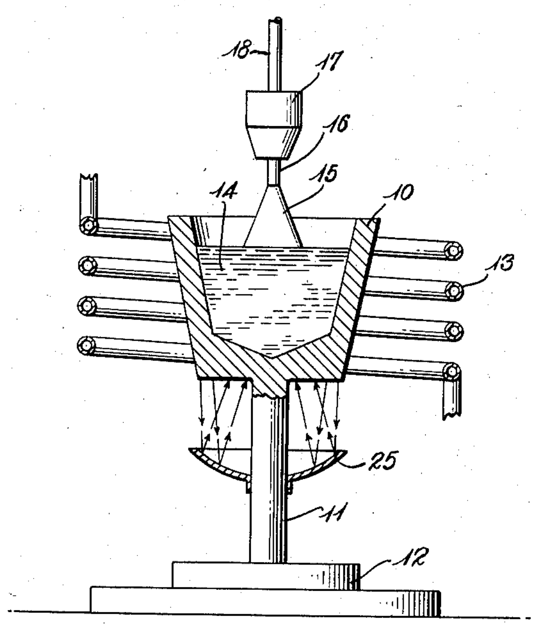


Fig. 2.

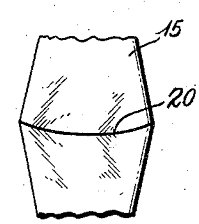
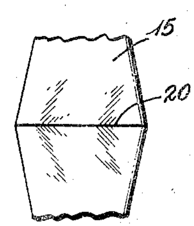


Fig. 3.



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METHOD AND APPARATUS FOR GROWING SEMICONDUCTOR CRYSTALS

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This invention relates to a method and apparatus for growing crystals from melts, and particularly to a method and apparatus for growing semiconductor crystals especially adapted for use in electrical transistors or diodes.

It is well-known to grow a crystal of semiconductor material from a melt and to alter the composition or conditions of growth of the crystal during its formation so as to produce one or more interfaces or junctions extending transversely across the crystal, at which interface or interfaces the electrical conductivity characteristic of the crystal changes. For example, a portion of a crystal may be grown to have an n-type conductivity, a small amount of an impurity added to change the type of crystal being grown to p-type conductivity, thus forming an interface extending across the crystal where this change takes place. Subsequently, an additional impurity of another type may be added to cause the crystal conductivity to change back to the n-type, thus forming a second interface. In many cases these interfaces are caused to lie quite close together, and they are usually caused to lie about midway between the upper and lower ends of the crystal as it is grown. Much the same result may be achieved by changing the rate of crystal growth, instead of changing the composition of the melt from which the crystal is being grown.

Crystal-pulling machines, useful in producing semiconductor crystals for electrical purposes, are well-known. One such machine is shown on pages 205 and 206 in the Coblenz and Owens book, "Transistors: Theory and Applications," published in 1955 by McGraw-Hill Book Company, Incorporated, of New York. In the pulling process, purified germanium, silicon, or other semiconductor material is melted in a crucible, and into this melt, maintained at a temperature barely above the melting point, a seed of like material is lowered. This seed is a small piece of single crystal so oriented with relation to the surface of the molten semiconductor material as to determine the orientation of the resulting crystal which is to be formed on it. As the seed is brought into contact with the surface of the melt and slowly withdrawn, the material of the melt adheres to it and grows onto the seed to form a single crystal. Crystals weighing approximately 100 grams or more are commonly grown and then cut into small sections for transistor or diode applications. Close temperature control is essential to the pulling process, and heat is generally applied by an electrical induction coil that surrounds the melt. Temperature controllers, accurate to the order of 0.1° C. or better, have been developed for this purpose. The seed crystal is generally rotated as it is withdrawn, and quite often subjected to a small amplitude vibratory motion as well. The rotation of the crystal is generally about 100 R. P. M., although considerable variation is possible.

After a crystal has been formed so that it has one or more transverse interfaces or junctions at which the conductivity type changes, the crystal is generally cut into a series of very small bars that extend vertically of the crystal and across the junction or junctions that it is desired to use. A typical dimension for these bars is .030 by .030 inch in cross-section and .25 inch long. In order to cut these from a crystal, it is usually desirable to cut the crystal transversely above and below the junction or junctions and then slice the transverse section that contains the junctions by a series of parallel vertical cuts in one direction and another series at 90° thereto.

A rather serious difficulty is encountered in this process because the interfaces or junctions that occur in crystals prepared according to known methods are not planar, but are curved, generally like a section of a sphere, this curvature being caused by the shape of the isotherm in the melt. Thus, if a section is cut from a crystal by two transverse planar cuts, one above and one below the junctions, the junctions will be only generally parallel to the two transverse cuts.

As a result, when the horizontal section containing the junctions is sliced by the vertical cuts into a series of transistor sections, the junctions or interfaces may occur at the middle of some of these sections, but, for the most part, the junctions or interfaces will occur toward one end or the other of the sections. This is highly undesirable, since the position of the junctions relative to the ends of the transistor sections determines the resistance of the emitter and the collector portions of the transistor, and also determines where the connection must be made with the base layer.

The purpose of the present invention is to avoid or alleviate the mentioned difficulty and to form semiconductor crystals containing junctions or interfaces that are substantially planar, as distinguished from being curved or arcuate.

Experience with the crystal pullers now in use indicates that the drawing of the crystal from the center of the molten mass tends to cool the center part of the molten mass to a temperature that is slightly below that at which the remainder of the mass of molten material is maintained, and this slight lowering of the temperature causes the crystallization to proceed more rapidly at the center of the crystal, and hence, when an interface or junction is formed, it curves downwardly from the edges of the crystal toward the center.

Broadly, the present invention comprises a method of supplying supplemental heat to the melt from which the crystal is growing at or near the center of the melt, in a quantity sufficient to balance the loss of heat from the center of the melt and overcome the tendency of the interface between liquid and solid to be arcuate. The result is a substantially planar interface which lends itself particularly well to the manufacture of transistor segments.

There are several ways in which heat can be applied to straighten the interface in a crystal being grown from a melt, and the basic method of this invention may be applied not only to the growing of germanium and silicon crystals containing interfaces for use in transistors, but in any crystal-growing situation in which it is desired to have the solidification take place in a plane rather than in a curve or arc. However, the invention is particularly useful in the formation of semiconductor crystals for electrical purposes.

Furthermore, although there are a number of ways in which heat may be applied to flatten the interface, a particular method and apparatus have been discovered for accomplishing this in the present circumstances, and this method and apparatus, because of their simplicity and adaptability to these particular circumstances, form an important part of this invention.

In the usual crystal-puller, the crucible in which the material that is to be pulled into a crystal is to be melted is mounted upon a support which extends upwardly from a fixed base. This support holds the crucible up inside of an induction coil or coils that induce a current in the crucible containing the material from which the crystal is being formed, so as to heat that material. According to this invention, it has been found that if a reflector is positioned a short distance below the crucible and arranged so that it is generally focused toward the center of the crucible, this reflector will pick up heat radiated from the crucible and reflect it back near the center of the bottom of the crucible, thus tending to supply heat where it will flatten the interface between the solid material in the crystal and the molten material in the crucible. If the reflector is of conductive material it will also heat due to electrical current from the induction coil, and this will tend to heat it further and to contribute to the heat reflected to the center portion of the melt upon which it is focused.

The details of this invention and the preferred form thereof will appear more clearly from the following description of the preferred form thereof, and from the appended drawings, in which:

Figure 1 is a vertical view of the parts of a crystal-pulling machine, with which this invention is concerned, certain parts being sectioned for better illustration;

Figure 2 is a diagrammatic illustration of a part of a crystal formed in the conventional manner, and cut vertically through the center to show the curvature of the interface where the conductivity type changes from one type to another; and

Figure 3 is a similar diagrammatic showing of a section of a part of a crystal formed in accordance with the principles of this invention.

As illustrated in Figure 1, a crucible 10 is mounted upon a vertical supporting member 11, which, in turn, is mounted upon a base 12. An induction coil 13 is positioned to surround the crucible, and is supplied with high-frequency current from a source not shown, so that it will induce a current into the crucible containing a quantity of semiconductor material and thus melt the semiconductor material and maintain it at the desired temperature. The crucible 10 is shown as containing a molten semiconductor material 14, from which there is being drawn a crystal 15 of semiconductor material attached a seed crystal 16, which, in turn, is held in a chuck 17, which is being simultaneously rotated and withdrawn from the melt by means of a shaft 18 powered by conventional means.

In the normal process of crystal pulling, the seed crystal 16 is lowered until it contacts the melt 14, and then withdrawn, forming the crystal 15, the melt 14 being maintained at exactly the right temperature for this purpose. As the crystal 15 is formed, the interface between the solid portion of the crystal and the melt is generally arcuate, as shown at 20 in Figure 2. Thus, when a change is made that causes the conductivity type of the crystal to change, the interface or junction has the arcuate shape indicated at 20 in Figure 2, and when the attempt is made to cut a series of vertically extending segments out of such a crystal, it becomes necessary to make these much longer than their final length, and then trim the ends off of each crystal segment separately to place the interface somewhere near the middle of the segment.

In accordance with this invention, a reflector 25, of unpolished tantalum or other suitable material, is mounted upon the supporting member 11 (in Figure 1), and this reflector 25 is so shaped that heat radiated from the bottom of the crucible will be reflected back toward the bottom of the crucible and toward the center of the crucible. This is shown by the arrows in Figure 1. The exact shape of this reflector is not critical, but it is generally concave, and it is convenient to mount it on the support 11, although, of course, it may be mounted in any other manner desirable.

If the reflector 25 is made of conductive material, as it usually will be, a certain amount of current is induced in it by the induction coil 13, and this current tends to heat the reflector and add to the heat supplied to the bottom center of the crucible. By moving the reflector up and down the support 11, an adjustment of the relative temperature may be made, thus adjusting the shape of the interface. By proper positioning of the reflector 25, the interface 20 may be caused to be substantially planar, as indicated at 20 in Figure 3.

Thus, there has been described a single specific method and embodiment of an apparatus suitable for growing semiconductor crystals especially adapted for use in electrical transistors or diodes. However, it is apparent that further modifications and changes may be made in this method and apparatus without departing from the scope of the invention as disclosed herein. Accordingly, it is the intent of this invention to claim all such modifications and changes as are within the scope of the appended claims.

What is claimed is:

1. A method of growing crystals from a melt that comprises maintaining the melt at a temperature at which a crystal will grow therefrom, bringing a seed crystal into contact with the surface of the melt and withdrawing it at a rate such as will draw a crystal thereon, and applying supplemental heat to a central portion at the bottom of said melt to produce a substantially planar interface between said crystal and said melt during the crystal growing process.

2. A method of growing semiconductor crystals that contain at least one p-n junction, from a melt, that comprises maintaining the melt at a temperature at which a crystal will grow therefrom, bringing a seed crystal into contact with the surface of the melt and withdrawing it at a rate such as will draw a crystal thereon, changing the conditions of crystal growth so as to cause the formation of a junction interface, and applying supplemental heat to a central portion at the bottom of said melt to produce a substantially planar interface between said crystal and said melt during the growing process.

3. A method as defined in claim 2 in which the conditions of crystal growth are changed by the addition of a small amount of an element that will affect the conductivity type of the crystal.

4. A method of growing crystals from a melt that comprises maintaining the melt at a temperature at which a crystal will grow therefrom, bringing a seed crystal into contact with the surface of the melt and withdrawing it at a rate such as will draw a crystal thereon, and intercepting heat radiation from the melt and its container and redirecting that heat radiation back onto the center of the bottom of the melt and its container so as to heat the center part of the melt and flatten the interface between the growing crystal and the melt during the growing process.

5. An apparatus for growing crystals from a melt that comprises means for containing the melt and means for heating the melt to a temperature at which a crystal will grow therefrom, means for bringing a seed crystal into contact with the surface of the melt and withdrawing it at a rate such as will draw a crystal thereon, and a concave reflector positioned underneath the melt-containing means and shaped so as to receive radiated heat from the melt and melt-containing means and redirect that heat onto the center portion of the bottom of the melt-containing means to produce a substantially planar interface between the growing crystal and the melt during the growing process.

6. An apparatus for growing crystals from a melt that comprises a crucible for containing the melt, a vertical support for said crucible below said crucible, an induction coil surrounding said crucible for heating the contents thereof to a temperature at which a crystal will

grow therefrom, a chuck for holding a seed crystal and means for rotating said chuck and reciprocating said chuck in a vertical direction so that the seed crystal may be brought into contact with the surface of a molten material held within the crucible and then withdrawn at such a rate as will draw a crystal thereon, and a concave reflector mounted on the vertical support below the crucible and positioned to receive heat radiation from the crucible and its contents and to redirect that heat radiation onto the bottom center portion of the crucible so as to control the shape of the interface between the growing crystal and the melt during the growing process.

7. An apparatus as defined in claim 6 which further includes means for adding a small amount of impurity to the melt to change the conductivity type of the melt and form a junction interface during the growth of the crystal.

8. An apparatus as defined in claim 6 in which the reflector is adjustably positioned on the vertical support.

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