

- [54] **BOAT STRUCTURE IN AN APPARATUS FOR MAKING SEMICONDUCTOR COMPOUND SINGLE CRYSTALS**
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 [58] Field of Search 23/273 SP, 301 SP

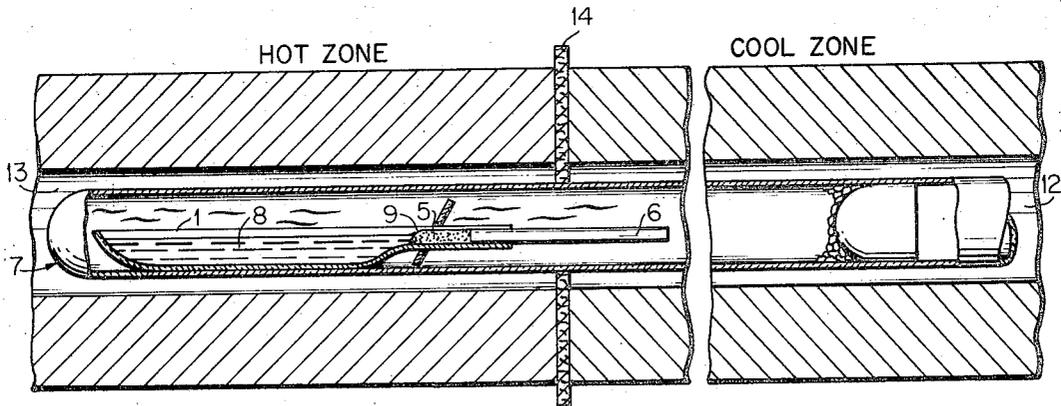
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[57] **ABSTRACT**

An apparatus useful for growing single crystal semiconductor material comprising a liquid melt section coaxially integrated with a seed cavity and having an annularly disposed integral thermal reflector means and a radiant heat dissipating member horizontally disposed and in a post linear direction from the seed cavity.

3 Claims, 4 Drawing Figures



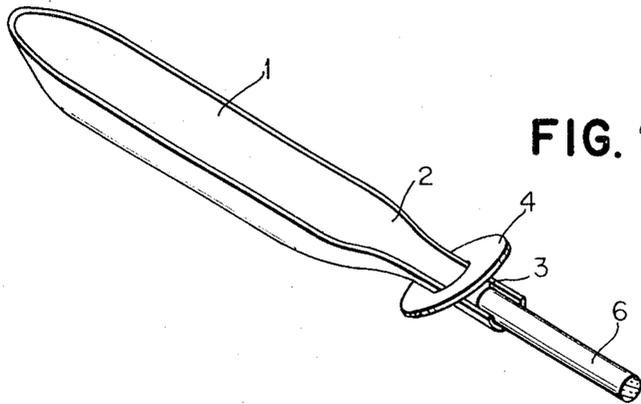


FIG. 1

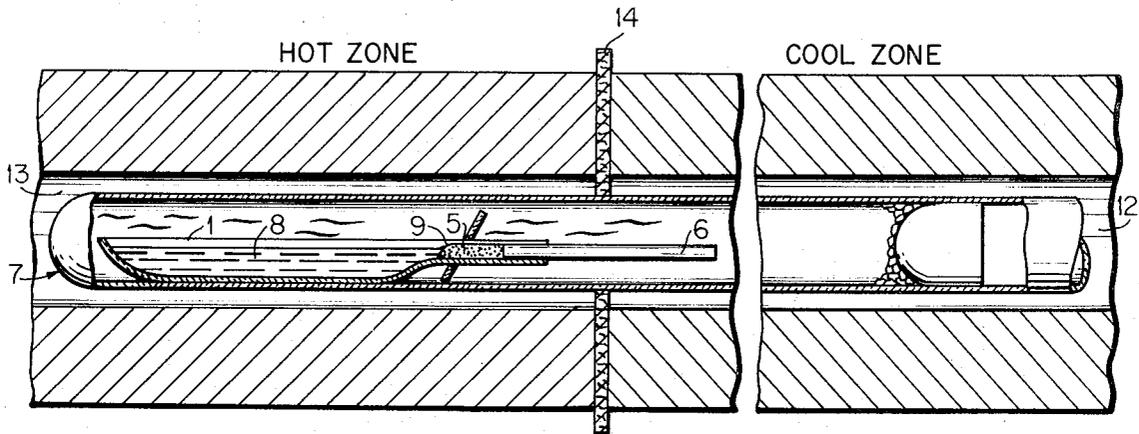


FIG. 2

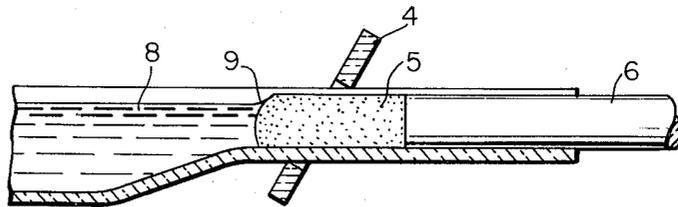


FIG. 3

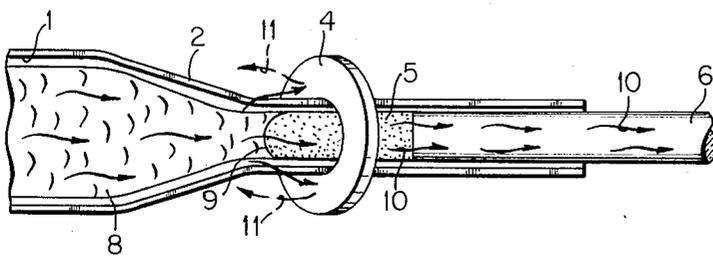


FIG. 4

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BOAT STRUCTURE IN AN APPARATUS FOR MAKING SEMICONDUCTOR COMPOUND SINGLE CRYSTALS

FIELD OF THE INVENTION

This invention relates to apparatus for making single crystal semiconductor compounds and especially relates to a method and apparatus for the preparation of Group III-V single crystal compounds such as gallium arsenide ingots and slices thereof, suitable for use as semiconductor structures.

BACKGROUND OF THE INVENTION

Doped and undoped single semiconductor crystals have been prepared or grown by a large variety of techniques. The most common involves the progressive, directional solidification of a molten semiconductor material from a starting seed crystal. The liquid is usually contained in a boat in contact with said single crystal seed. The solid liquid interface is moved away from the seed by motion of the boat, movement of the temperature gradient profile, or by pulling the seed from the melt. These methods are often referred to as the Horizontal Bridgman, Gradient Freeze and the Czochralski techniques.

In the Horizontal Bridgman method, crystals are grown in a sealed fused silica system in fused silica boats. The fused silica boat surfaces are usually sandblasted to produce a multi-faceted or disrupted surface in order to prevent wetting and avoid sticking or adhering of the produced material to the boat surface. Synthesis is usually performed from the elements in situ prior to growth. Usually, a two-zone furnace is employed to furnish two independently controllable temperature zones, one of which is at a higher temperature than the other. The hotter zone is controlled at a temperature above the melting point of the crystal to be grown. A thermal gradient of known characteristics is maintained at one end of this furnace. In practice, the boat containing the molten charge and a seed crystal of the desired orientation is situated in this gradient such that the point in the gradient corresponding to the melting temperature of the crystal is located at the point at which the solid-liquid interface is desired during the seeding of the melt. Relative motion of the boat with respect to the gradient results in directional freezing of the crystal.

The melt is usually comprised of a molten compound of the approximate stoichiometry of the crystal to be grown as a single crystal. The melt is usually held at a temperature above the melting point of the compound under an atmosphere of the more volatile element at a pressure approximately equal to the dissociation pressure of the compound at its melting point. T. S. Plaskett, et al., J. Electrochemical Society, Solid State Science, January 1971, pp. 115-117, describes the concept in relation to the production of gallium arsenide.

The prior art has taught certain boat structures having seed cavities associated with semi-cylindrical sections adapted for holding the liquid. These structures usually contain reactants and seed crystals promoting single crystal growth at temperatures between 600° to 1,300°C. Early teaching reveals a single semi-cylindrical vessel in which a seed crystal usually is embedded in a powdered material such as fused silica adjacent to a molten body of polycrystalline material to

produce a solid-liquid interface, the movement of which from a higher to a lower temperature produces a single crystal ingot conforming in part to the configuration of the vessel.

Subsequently, it was found desirable to incorporate a separate seed cavity adjacent to and associated with the liquid containing cavity in an attempt to obtain a proper neckdown of the growing seed crystal and to facilitate the growth of larger single crystal ingots from smaller seed crystals.

Prior structures utilized in single crystal horizontal growth did not maintain thermal symmetry about the crystal growth axis which hampered the desired and normal growth direction of the crystal along the horizontal axis of the boat. This condition nucleates unpredicted deviations from the normal growth axis which in turn voids the control of the geometry of the slice taken from the boule or ingot or results in polycrystalline growth. In addition, these prior structures could not maintain the orientation of the seed crystal with respect to the longitudinal axis of the boat. This also affects the crystalline characteristics and geometry of slices taken from boules or ingots grown in these structures.

Seed cavities having a rectangular shape do not allow freedom of movement of the seed in response to mechanical stress resulting from thermal discontinuities surrounding the melt. The seed becomes keyed in as a result of seed cavity wall distortions which results in stress being placed on the growing crystal due to differential thermal expansion.

The random or radial heat loss from the area surrounding the liquid-solid interface results in spurious growth and an undesirable twinning condition in the crystal growth process. Similarly, said heat loss causes localized polycrystalline growth which grossly deteriorates the yield of crystal growth.

U.S. Pat. No. 3,520,810 relating to a process for the production of gallium arsenide illustrates the prior art apparatus having the disadvantages recited heretofore.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an apparatus for the horizontal growth of doped or undoped single crystals adaptable for use as semiconductor structures.

It is a further object of this invention to provide an apparatus for the horizontal growth of single crystal semiconductor materials wherein the direction of the crystal growth is along the horizontal axis of the growth vessel without significant deviation therefrom.

It is still a further object of this invention to provide a semiconductor single crystal growth apparatus having a seed cavity adaptable to utilizing minimum seed material.

Another object of this invention is to provide an apparatus for the monocrystalline growth of semiconductor material whereby the resultant boule or ingot is of such nature as to provide maximum control of the geometry of slices cut therefrom.

The aforesaid and other objects are accomplished by providing a monocrystalline semiconductor growth apparatus adaptable to providing a sharp temperature gradient at the solid-liquid interface of the crystal growth process and providing means for axially dissipating radiant heat energy from the hot to the cold segments of the process furnace and heating apparatus.

The foregoing and other objects, features and advantages of the invention and the accomplishment thereof will be apparent from the following more particular description of preferred embodiments of the invention as illustrated in the accompanying drawing and examples.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a boat apparatus for the growth of single crystal material showing a semicylindrical liquid containing section and an adjacent coaxial semi-conical section adjacent to said liquid containing section and the semi-cylindrical seed section or cavity with its associated radiant heat pipe and reflector.

FIG. 2 is a cross-sectional fragmented view of the crystal growing apparatus contained in a sealed tube which in turn is enclosed in a multizone furnace.

FIG. 3 is a cross-sectional fragmented view of the monocrystalline growing apparatus showing the liquid solid seed interface with the heat shield and the radiant heat dissipating member.

FIG. 4 is a fragmented top plan view showing the solid-liquid interface contained in the crystal growing apparatus and the associated heat shield and radiant energy conducting means.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, FIG. 1 illustrates a specific configuration of the single crystal semiconductor crystal growing apparatus. Typically, the apparatus is constructed of clear fused silica having a sand-blasted or roughened surface which avoids wetting of the interior surface by the molten liquid material. The illustrative configuration of the liquid containing or melt section 1 is connected by a semi-conical coaxial transition section 2 to a coaxial semi-cylindrical seed containing section 3 of smaller radius than the melt section 1.

An integral tilted reflection member 4 annularly surrounding the seed cavity 3 near the center of seed 5 is provided. Said reflecting means redirects radial heat flow from and about the conical coaxial section 2 backward and toward said section 2 illustrated in FIG. 4 by arrows 11; thereby preventing radial heat losses from the said conical section. The resultant temperature stabilization prevents localized cold spots which produce polycrystalline nucleation which decreases the ultimate quality of the single crystal boule which in turn decreases yield.

The radiant energy conducting means 6 is a solid cylinder of clean smooth and non-sandblasted fused silica having flame polished ends. This cylinder or light pipe conducts radiant energy longitudinally along the axis of the apparatus toward a colder furnace section subsequently explained and illustrated in reference to FIG. 2. The apparatus constructed as illustrated and utilized in the process of single semiconductor crystal growth creates a radial thermal symmetry which enhances crystal growth along the horizontal axis of the apparatus without significant deviation therefrom.

FIG. 2 illustrates the crystal growing apparatus contained in a closed tube 7 which is in turn contained in a double or dual zone furnace arrangement whereby the hot zone is maintained at a temperature to keep the molten material at 8 in a molten condition and sustains

a solid liquid interface at 9 between the molten polycrystalline material 8 and the solid seed 5.

The solid-liquid interface at 9 is maintained in a slightly convex configuration in the direction of the molten material. This solid-liquid interface configuration results from the relatively higher horizontal heat flow with respect to the radial heat flow through the longitudinal heat conducting member 6 and illustrated by the arrows 10 in FIG. 4. Where the relative amount of heat flow in the vicinity of the liquid-solid interface is radial, the interface configuration is concave toward the molten charge and detrimental to the growth of crystals with a high degree of perfection.

The single crystal growth apparatus of this invention is further described in connection with its application to the well known process for making doped or undoped gallium arsenide and known as the Horizontal Bridgman technique.

Broadly, stoichiometric quantities of gallium and arsenic are reacted in a closed tube which is subjected to a temperature gradient of approximately 614° to 1,240°C. Arsenic vaporized at the said 614°C temperature and a gallium arsenide solid-liquid crystallization interface exists at about 1,240°C.

A double furnace apparatus as shown in FIG. 2 is provided having a cold zone 12 and a hot zone 13 and separated by an insulating partition 14. A stoichiometric amount of polycrystalline gallium is placed in the liquid melt section 1 of the apparatus with a given amount of the desired dopant. A previously prepared seed of the desired crystallographic orientation is inserted into the seed cavity.

The apparatus containing the aforesaid materials is placed in a tube with a sufficient amount of arsenic to maintain the stoichiometry of the melt plus an excess to maintain a condensed phase at one atmosphere of pressure at about 614°C.

A seal off plug is inserted into the tube and the tube evacuated to 10⁻⁶ Torr, whereupon the tube is conventionally sealed off by collapsing the tube onto the plug.

The tube is now inserted into the furnace and brought to thermal equilibrium and positioned so that the gallium and dopant material are located in the hot section of the furnace and maintained in a molten state. The liquid solid interface between the molten polycrystalline gallium and the seed crystal is located at a temperature of about 1,240°C in the thermal gradient.

The tube is then moved at the desired crystal growth rate and with respect to the furnace from the hot zone toward the colder zone while maintaining the solid-liquid interface between the molten gallium arsenide and the seed crystal within the said 1,240°C temperature zone. This results in a horizontal directional freezing or crystallization of the charge. Upon completion of the crystallization of the molten charge, the tube is allowed to slowly cool to room temperature, whereby thermal shock is avoided, whereupon the tube is broken open and the apparatus containing the gallium arsenide ingot is removed.

The ingot or boule thus formed is preserved for further processing.

The use of previously known crystal growing apparatus to produce gallium arsenide ingots produced acceptable product less than 10 percent of the time, while the utilization of the apparatus of this invention produced product yields greater than 60 percent. Simi-

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larly, the reproducibility of the desired crystal orientation with respect to its longitudinal axis was greatly enhanced and improved by this apparatus. Likewise, this apparatus allows the constant reproducibility of slice geometry which is necessary and required for production type fixtures and manufacturing efficiency.

It should be clearly understood that although an apparatus having a semi-cylindrical shape is specifically illustrated, the invention herein described is not limited thereto.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. An apparatus for growing monocrystalline semi-

conductor material comprising a primary concave boat section adapted to contain a melt and an integral concave end section having a decreased depth and width relative to said concave primary boat section and adapted to hold a seed crystal contacting said melt, the primary and end sections disposed axially, said end section having a disc shaped radiant heat reflecting means angularly and annularly disposed to the boat axis and a heat dissipating means secured in the distal portion of said end section and extending externally thereof and forming an end section closure.

2. An apparatus in accordance with claim 1 wherein said apparatus is constructed of fused silica.

3. An apparatus in accordance with claim 1 wherein the apparatus is constructed of fused silica and having roughened surfaces except said radiant heat dissipating member.

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