

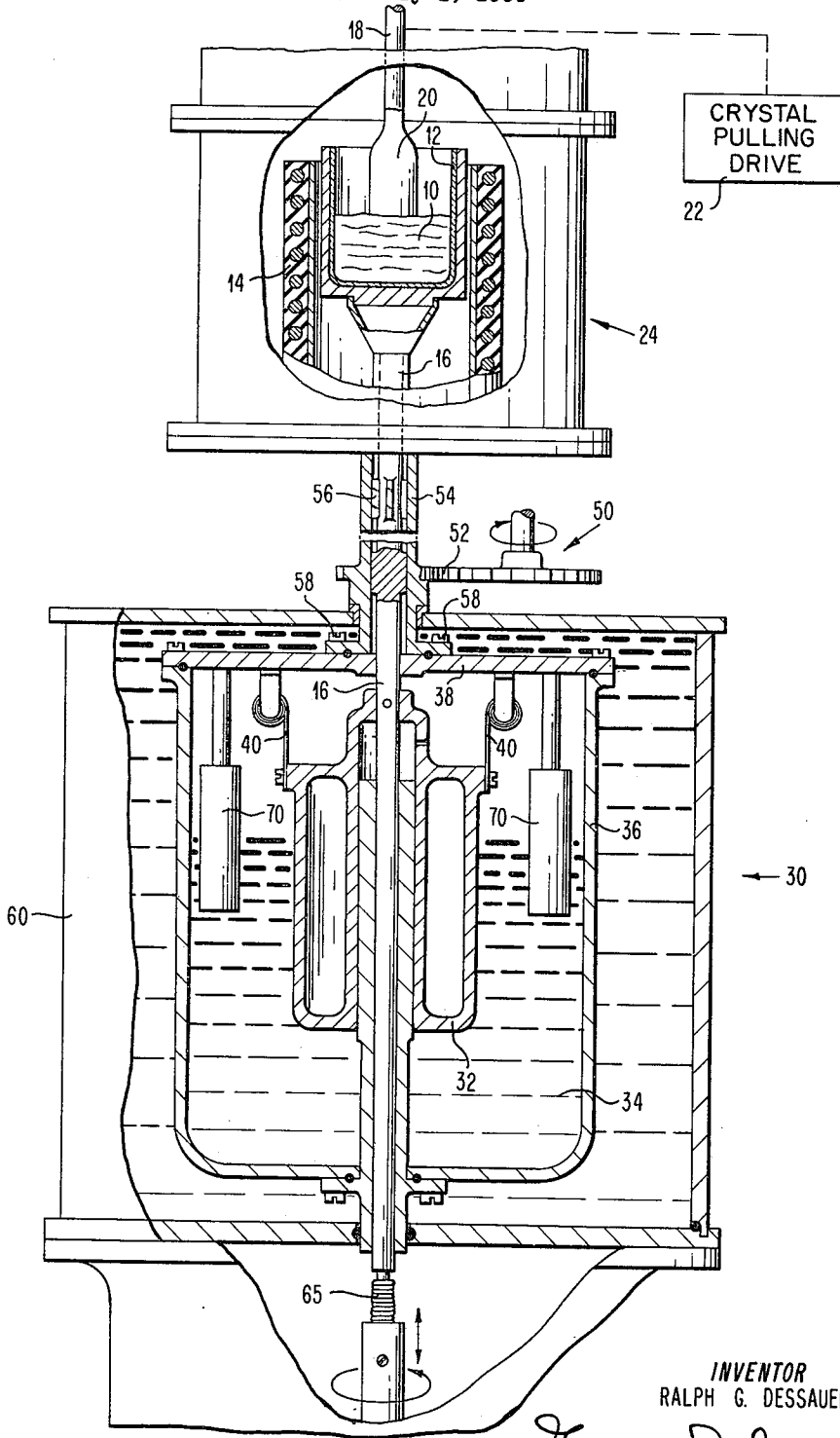
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BUOYANT DEVICE IN CRYSTAL GROWING

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**BUOYANT DEVICE IN CRYSTAL GROWING**

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8 Claims

**ABSTRACT OF THE DISCLOSURE**

A buoyant force mechanism, which includes a float suspended from one end of the shaft in a flotation fluid, is used for moving a shaft in response to a heavier or lighter force at the other end of the shaft. The flotation fluid is located within a tank. The weight of the float and other assembly parts is supported by use of a constant force spring means which may be attached to the tank. The use of the buoyant force device in an apparatus for growing a crystal from a melt is particularly valuable.

This invention relates to a buoyant force device which is effective in moving a shaft by means of its buoyant characteristic and more particularly to the use of such device in a system for automatically drawing an elongated crystal from a melt of material.

Crystals have been grown from melts for many years. However, the requirement for large quantities of high quality crystals has not come about until quite recently. This requirement is particularly needed in the semiconductor industry. Drawing large single crystals to close diameter tolerances is an important phase of the mass production of semiconductor devices.

One of the most widely used techniques in drawing semiconductor single crystals is the Czochralski pulling method. The high purity semiconductor material is melted in a container and the temperature is maintained just above the freezing point of the material. A particularly oriented seed crystal is then dipped into the melt and the seed is slowly raised from the melt. The melt liquid adheres to the seed by surface tension and adhesive forces, and under the correct conditions the crystal will grow as it is slowly pulled away from the melt.

The diameter of the crystals grown by the Czochralski method is a function of many varying conditions. Close and constant attention by highly skilled operators is required to obtain crystal diameters within acceptable limits. A solution to this operator problem in the form of a control system for automatically drawing an elongated crystal from a melt of material is described in patent application Ser. No. 530,819 (IBM Docket 14,472) entitled "Control System," filed Mar. 1, 1966 by R. G. Dessauer, E. J. Patzner and M. R. Poponiak and assigned to the same assignee as the present invention. In this control system a radiation detector is utilized for sensing radiation propagating from the melt and for providing an output proportional to the amount of radiation sensed. The output of the radiation detector is applied to a means for adjusting the growth condition of the crystal. Adjustment of the growth condition is accomplished by means of adjusting the crystal pulling mechanism, the container lift, the container rotation rate or combinations of these mechanisms. While this invention is a substantial improvement over the prior art, it is not readily possible to maintain the melt at a constant level with respect to the heater means. The importance of maintaining the melt at a constant heater position is for uniform heating. Further, where used with the above referred to patent application, the radiation detector will

always be focused onto the melt-crystal interface because the melt level will not change.

It is thus an object of the present invention to provide a new buoyant force device for moving a shaft in response to a heavier or lighter force at the other end of the shaft.

It is another object of the present invention to provide an improved system for growing elongated crystals from a melt of material.

It is a further object of this invention to provide a system for growing elongated crystals wherein a buoyant force device is used to maintain the melt-crystal interface at a constant level during the entire crystal growing period.

These objects are accomplished in accordance with the broad aspects of the present invention by providing at one end of a shaft a means which is responsive to a change in weight of the article at the other end of the shaft to maintain the level of the article at the other end of the shaft. This is accomplished by use of a buoyant force mechanism which includes a float suspended from one end of the shaft in a flotation fluid. The flotation fluid. The flotation fluid is located within a tank. The weight of the float and other assembly parts is supported by use of constant force spring means which may be attached to the tank.

The use of the buoyant force device in an apparatus for growing a crystal from a melt is particularly valuable. A container holding the melt is secured to the upper end of a vertically movable shaft and at the lower end is the means for vertically moving the shaft as the crystal grows to maintain the melt-crystal interface at a constant level. Surrounding the container is a heater which maintains the melt-crystal interface just above the melting point of the material in the container. It is important that this interface level be maintained at a uniform level. The melt-crystal interface level will always be at the same location since the container is gradually raised as the melt is used up during the crystal growth due to the buoyant force of the device. The melt-crystal interface is therefore held at a uniform level with respect to the heater means which allows the temperature of the melt-crystal interface to be maintained almost precise the same during the entire crystal growth period. This greatly increases the quality of the crystal grown in that it reduces imperfections therein.

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

In the drawing:

FIGURE 1 is a partially in cross-section, schematic view of the apparatus of the present invention.

Referring now to FIGURE 1 there is shown an apparatus for growing semiconductor crystals such as silicon single crystals using the buoyant force device of the present invention. A silicon charge 10 is held in a container or a crucible 12 composed of a suitable material such as fused quartz. A suitable heater means such as resistance heater 14 is provided to maintain the silicon charge in its melted form, and just above the freezing point of the silicon at its melt-crystal interface. The container 12 is supported on the end of a vertically movable shaft 16. The shaft alternately may also be movable rotationally and vertically as illustrated in the drawing. Means (not shown) are provided for holding a crystal seed on the end of crystal pulling shaft 18. The seed is dipped into the melt and withdrawn therefrom to grow a crystal 20. The crystal pulling means 18 serves both as the support for the crystal and for raising the crystal as it is being grown. A crystal pulling drive means 22 is used to

slowly raise the crystal pulling means 18. The furnace or oven bell jar 24 encloses the container and the heating means.

The means for vertically moving the shaft 16 as the crystal grows is the buoyant force device 30. The buoyant force device 30 includes a float means 32 attached to the shaft 16 for purposes of vertically moving the shaft 16. The float 32 is located in a flotation fluid 34 which is supported in a tank 36. The float means 32 is flexibly attached to the cover plate 38 of the tank means 36 by means of constant force means 40 which are used to support the approximate weight of the float means 32, the shaft 16, and the container 12. The illustrated means 40 are flat coil constant force springs. There may be two or more of these constant force spring means 40 to support the weight or float means, shaft and container in the flotation fluid 34.

As the weight of the melt is reduced by the crystal growth of crystal 20, the float means 2 gradually is raised and it raises the shaft 16 which in turn raises the container 12 and in turn maintains the melt-crystal interface at a uniform level in relation to the heater means 14.

It is preferred in the Czochralski crystal growing method to have the container rotate during crystal growth. Means 50 are therefore provided for rotating the shaft 16 and, in turn, the container 12. Such a rotating means may include a driven gear 52 which drives external shaft 54. The shaft 16 is connected to the external shaft 54 by a ball spline 56 which allows the vertical motion of the shaft 16 and at the same time allows the external shaft 54 to rotate the shaft 16. The external shaft 54 is illustrated as attached by screw means 58 to the tank coverplate 38. The tank and the float means 32 are therefore also rotated in this embodiment. It will be obvious to one skilled in the art that the tank and float means need not be rotated and appropriate modifications in the linkages could be made to accomplish this result.

The buoyant force mechanism is preferably positioned within a cooling jacket 60 so as to maintain the density of the flotation fluid at the desired value. This is important since the flotation fluid density affects the buoyant force of the float means 32. This is particularly important where cooling fluids such as perfluoroamine and ethers are used which have a steep temperature density curve. These fluoro-chemicals have higher densities than water and therefore can be used in conjunction with a smaller float means and other assembly parts. Provision can be made for an appropriate inlet and outlet (not shown) for circulating cooling water through the cooling water jacket 60.

A suitable sensing unit, shown schematically as 65, can sense how far the float means has risen and interpret this into the quantity of melt material remaining in the container 12 and the melt level with respect to the container. This information is continuously available to an operator on an indicator device (not shown). With this information, the maximum crystal growth can be obtained. Alternately, a linear velocity transducer can be used to give an indication of the rise velocity of the float. This is a continuous indication of crystal diameter where a constant crystal pull rate is maintained. Therefore, the output of the transducer can be used, for example, to adjust heater temperature to in turn control crystal diameter.

Centrifugal effects on the fluid level are small with the low rotational velocity usually used. They may, if necessary, be counteracted by adjusting the tank elevation when the float is rotating at operational velocity.

The relationship required to achieve the objective of continuously raising the container at a rate equal to that of the melt level drop in the container may be derived for constant cross-sectional tank float means and container. As the float rises out of the fluid, the fluid level drops and partially negates the rise of the float. The rise of the float

can, of course, never be totally negated since in that case the system will have returned to the initial conditions.

The design equation for the present device is determined by the following. It is required that there be no vertical displacement of the melt level relative to the tank,  $\Delta d_{m/t}$ . Therefore:

$$\Delta d_{m/t} = 0$$

The displacement of the melt level in the crucible,  $\Delta d_{m/c}$ , can be described in terms of the change in melt weight,  $\Delta W$ , and the melt cross-sectional area,  $A_m$ , and density,  $\rho_m$ , as:

$$\Delta d_{m/c} = \frac{\Delta W}{A_m \rho_m}$$

Using these equations the vertical displacement of the float in the tank,  $\Delta d_{f/t}$ , can be derived as:

$$\Delta d_{f/t} = - \frac{\Delta W}{A_m \rho_m} \quad (1)$$

Considering the tank and float only, by Archimedes' principle the change in melt weight,  $\Delta W$ , can be described in terms of the vertical displacement of the float in the fluid,  $\Delta d_{f/o}$ , the cross-sectional area of the float,  $A_f$ , and flotation fluid density,  $\rho_o$ , as:

$$\Delta W = \Delta d_{f/o} A_f \rho_o$$

Using this equation and considering that the total volume of flotation fluid remains constant during the operation, the vertical displacement of the float in the tank can be expressed in terms of the change in melt weight, flotation fluid density, and the tank and float cross-sectional areas,  $A_t$  and  $A_f$  respectively, as:

$$\Delta d_{f/t} = \frac{\Delta W}{\rho_o} \frac{1}{A_t} - \frac{1}{A_f} \quad (2)$$

The Equations 1 and 2 may be combined and the final design equation results:

$$\frac{1}{A_f} - \frac{1}{A_t} = \frac{1}{A_m} \frac{\rho_o}{\rho_m}$$

For different size containers 12 or different density melts 10 the weight change per inch of rise will differ. This can be accommodated by adjustment according to the design equations. This adjustment is readily accomplished changing the area of the tank  $A_t$  by means of the addition or removal of rods 70. The apparatus is thus a spring with a variable spring constant.

From the foregoing description, it will be seen that the buoyant force device is relatively simple in construction and is useful where a uniformly variable vertical force of variable rate is required without fatigue and friction inherent in springs in general. The device is useful where it is desired to keep the surface level elevation of a fluid or a powder constant in a container as fluid is added to or subtracted from the container. The device has been shown as a great value, particularly as a component part of an automated crystal growth system.

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 details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. An apparatus for growing a crystal from a melt comprising:

- a container for holding said melt;
- a heater means having a uniform heat level at the melt-crystal interface surrounding said container;
- crystal pulling means for raising the said crystal as it is being grown;
- a vertically and rotationally movable shaft supporting said container;

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means for constantly rotating said shaft and, in turn, said container;  
 means for vertically moving said shaft as the crystal grows to maintain said melt-crystal interface at said uniform heat level; and  
 said means for vertically moving includes a float means attached to said shaft which float means is suspended in a floatation fluid within a tank so that the said shaft and said container are slowly moved upward by buoyant force as the crystal grows.  
 2. The apparatus of claim 1 further comprising constant force means attached to said tank for substantially supporting the weight of said float means, said shaft and said container so that only the weight of said melt is supported by said buoyant force.  
 3. The apparatus of claim 1 further comprising means for changing the cross-sectional area of said tank.  
 4. An apparatus for growing a crystal from a melt comprising:  
 a container for holding said melt;  
 crystal pulling means for raising the said crystal as it is being grown;  
 a vertically movable shaft supporting said container;  
 a float means attached to said shaft; and  
 said float means being suspended in a floatation fluid within a tank so that the said shaft and said container are slowly moved upward by buoyant force as the crystal growth continues and the melt-crystal interface is maintained at a constant level.  
 5. The apparatus of claim 4 wherein said shaft is additionally rotationally movable and further comprising means for rotationally moving said shaft and, in turn, said container.  
 6. The apparatus of claim 4 further comprising means for changing the cross-sectional area of said tank.  
 7. An apparatus for growing a crystal from a melt comprising:  
 a container for holding said melt;  
 a heater means having a uniform heat level at the melt-crystal interface surrounding said container;  
 a seed-holder for drawing a seed from the container;  
 crystal pulling means attached to said seed-holder for raising the said crystal as it is being grown;

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means for advancing and rotating the container as the melt therein depletes;  
 said means for advancing and depleting includes a splined shaft supporting the container mounted with an external shaft for rotation therewith about the shaft axis and for axial movement therein;  
 means for rotating the external shaft;  
 tank means with a liquid having a level therein fixed to said external shaft and rotatable therewith;  
 said spline shaft extending into said tank and having a float mounted thereon;  
 the said float secured to said tank through a constant force spring;  
 and said float responding to a depletion of the melt for advancing the spline shaft axially upward through the external shaft.  
 8. The apparatus of claim 7, further comprising means for changing the cross-sectional area of said tank.

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