

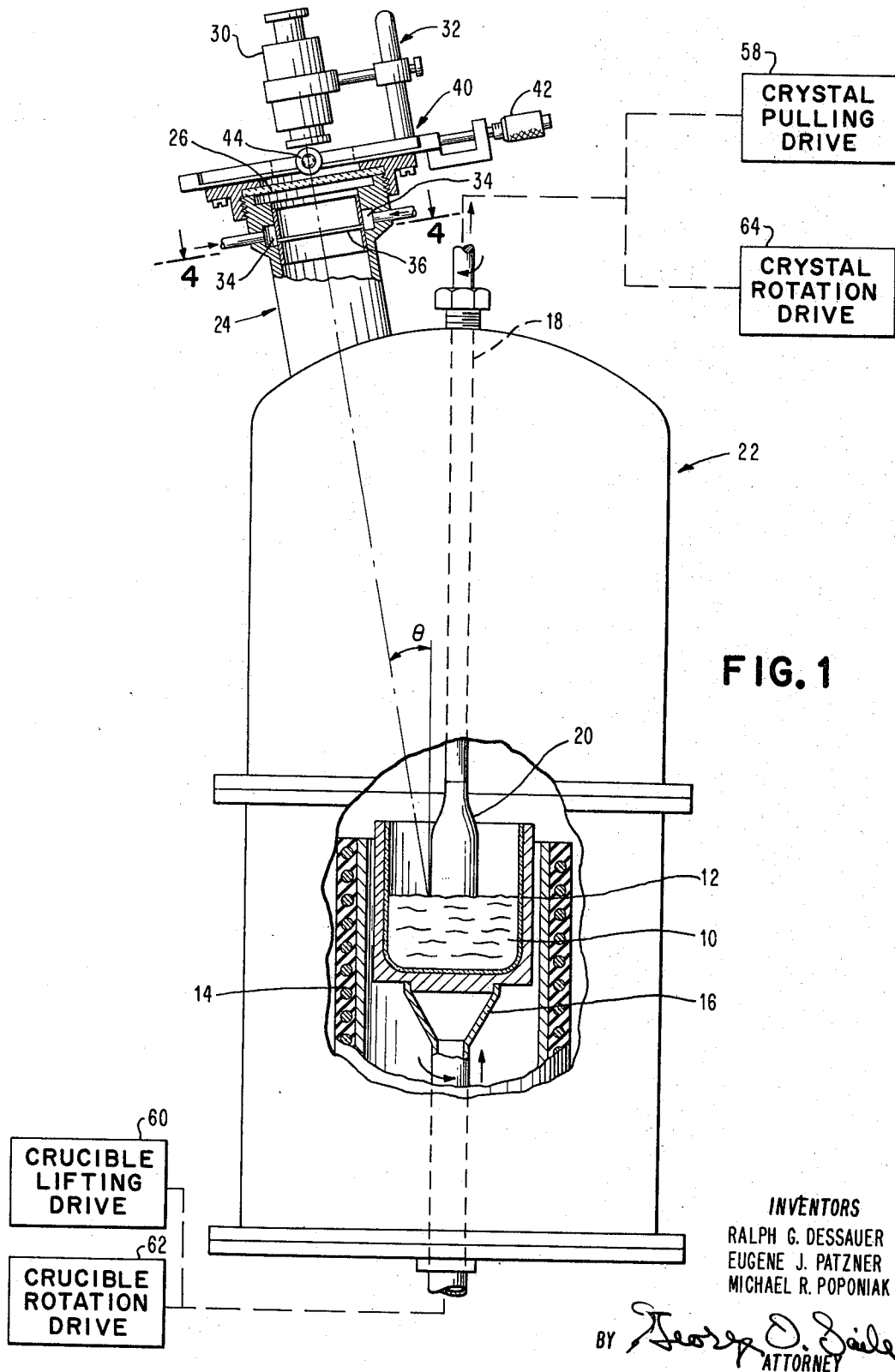
Feb. 3, 1970

R. G. DESSAUER ET AL
RADIATION SENSITIVE CONTROL SYSTEM FOR CRYSTAL
GROWING APPARATUS

3,493,770

Filed March 1, 1966

2 Sheets-Sheet 1



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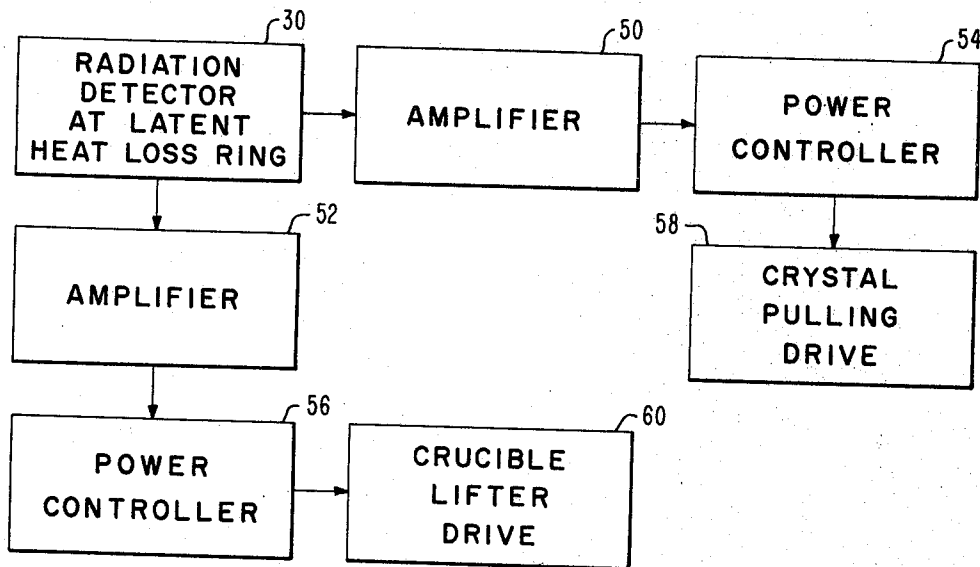


FIG. 2

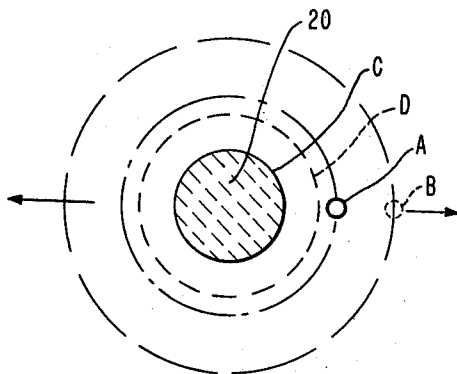


FIG. 3

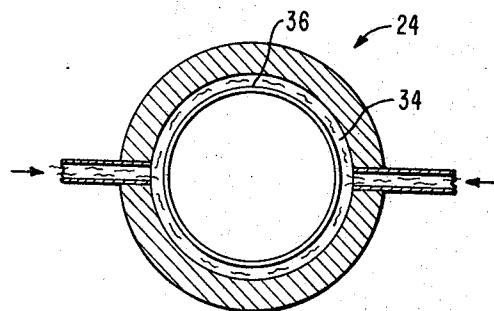


FIG. 4

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RADIATION SENSITIVE CONTROL SYSTEM FOR CRYSTAL GROWING APPARATUS

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7 Claims

ABSTRACT OF THE DISCLOSURE

A control system for automatically drawing an elongated crystal from a melt of material which includes a radiation detector for sensing radiation derived and propagating from the melt and for providing an output proportional to the amount of radiation sensed. The output of the sensed radiation is applied to a means for adjusting the growth conditions of the crystal. The adjustment of the growth conditions is accomplished by means of adjusting the crystal pulling mechanism, the container lift mechanism, the container rotation rate, other growth parameters or combinations of these methods.

This invention relates to a control 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. Even with the use of highly skilled operators a uniform crystal diameter is not obtainable. Therefore, following the growth of the crystal the diameter of the crystal must be made uniform through grinding and other tooling techniques. This grinding step is a waste of material and can have adverse effects on the structure of the crystal itself.

It is thus an object of the present invention to provide a new control system for automatically growing elongated crystals from a melt of material.

It is another object of the present invention to provide a system for automatically growing elongated, controlled diameter crystals which do not require highly skilled labor to grow or excessive grinding steps to reduce the grown crystal to a uniform diameter.

It is a further object of this invention to provide a system for automatically growing an elongated, uniform diameter silicon crystal from a melt of silicon wherein the crystal diameter can be controlled within a very small fraction of an inch.

These objects are accomplished in accordance with the

present invention wherein the control system includes a radiation detector for sensing radiation propagating from the melt and for providing an output proportional to the amount of radiation sensed. The output of the sensed radiation is applied to a means for adjusting the growth conditions of the crystal. The adjustment of the growth conditions is accomplished by means of adjusting the crystal pulling mechanism, the container lift mechanism, the container rotation rate or combinations of these mechanisms.

It has been determined that the optimum adjustment for automatically growing elongated, controlled diameter crystals from a melt of material is accomplished by positioning the radiation detector so as to place its field of view on the surface of the melt just adjacent to the crystal being grown and having the detector's resultant output used to adjust the pulling rate of the crystal pulling means and the lifting rate of the container lifting means simultaneously. Controlling these rates in this manner has been found to provide the fastest response to thermal condition variations at the melt surface. It is this fast response which produces the superior and automatic diameter control. The mechanism of control can be understood by the following examples. When the crystal diameter begins to increase, the increasing proximity of the crystal to the field of view area causes an increase in radiation pickup thus increasing the crystal pull and the container lift rate. The increase in crystal pull and container lift rate causes the crystal diameter to return to the desired value. The increased container lift rate dampens out this process and acts to keep the melt level constant with respect to the sensing element.

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 drawings.

In the drawing:

FIGURE 1 is a partly in cross section, schematic view of the control system of the invention for automatically drawing an elongated crystal;

FIGURE 2 is a block diagram of a preferred control system;

FIGURE 3 is a diagrammatic illustration of a procedure used to set the diameter of the crystal being grown; and

FIGURE 4 is a cross sectional view taken along line 4—4 of FIGURE 1 showing the means for providing a gas shield over the internal surface of the view port.

Referring now to FIGURE 1 there is shown an apparatus for drawing semiconductor crystals such as silicon single crystals using the control system of the present invention. A silicon charge 10 is held in a container or 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 at a temperature just below the freezing point of the silicon. A container or crucible lifting means 16 supports the container or crucible 12. 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. The furnace or oven bell jar 22 encloses the crucible and heating means.

A special view port 24 is located on the furnace bell jar 22 at an angle θ slightly inclined from the vertical. The view path intersects the vertical axis of the furnace bell jar 22. The sight angle θ is made quite small to produce the greatest control system sensitivity. The smaller the slight angle θ , the less the effect of variations in the

melt level will effect the sensitivity of the control system. The preferred sight angle θ for crystal growth is about 5° to 10° when the crystal diameter is large in comparison to the crucible diameter.

The view port 24 has a sight glass 26 composed of a suitable optically clear material such as fused quartz which has been ground and polished. The radiation detector 30 is positioned above the view glass 26 by supporting means 32 for positioning the detector so as to place its field of view on the surface of the melt adjacent to the crystal being grown.

Referring now to FIGURE 4 in addition to FIGURE 1, on the melt side of the view glass 26, a gas shield is established over the surface of the glass 26 to keep the sight glass free from deposits such as silicon monoxide, dopants and so forth. This shield acts to prevent a reduction in signal from the radiation detector 30 due to blockage of radiation by these deposits. The gas shield is accomplished by feeding an inert gas such as argon into an integral passage 34 encircling the view port 24. The gas is forced from the passage 34, through slit 36 into the central portion of the view port 24.

An X-Y positioner 40 allows the movement of the field of view of the radiation detector 30 to set the diameter of the crystal. The micrometers 42 and 44 are the means shown in the drawing by which the detector 30 can be moved. Alternate means can, of course, be substituted for the micrometer structure. FIGURE 3 illustrates the effect of this movement. The movement of the field of view of the detector 30 from position A to position B results in the increase in the diameter of the crystal 20 from position C to position D. This effect is caused by the control system. The mechanism is explained by the fact that since the field of view position B initially has a lower amount of radiation propagating from its surface, the crystal pulling and/or crucible lifting rates are decreased until the crystal diameter increases to the point where a new equilibrium is brought about. By this adjustment during the growth of an elongated crystal, crystal shapes of almost any description can be obtained. A programmed drive mechanism (not shown) could be substituted for the micrometer 42 so as to produce automatically controlled crystal shapes of any desired and controlled diameters throughout the length of the elongated crystal.

The radiation detector 30 can be of any desired type such as photoconductors, photovoltaic cells, etc. It is preferred that the device be sensitive to both visible and infrared radiation so as to have the greatest possible sensitivity to changes in melt radiation. The detector preferably has a small field of view. The particular type of radiation detector used will vary from type to type of crystal being grown, because of the type of radiation emitted, the quantity of radiation emitted and the radiation's spectral characteristic. The preferred radiation detector for silicon crystal growing is a photovoltaic optical pyrometer having a field of view of 0.1 inch diameter. The instrument operates in a spectral region from about 0.65 to 0.9 micron. It is calibrated for emissivity of 0.7. The detector's output signal is continuous and directly proportional to the intensity of radiation focused by the lens of the pyrometer on its photovoltaic cell. Radiation intensity through the eye piece of the pyrometer is controlled by a dimmer consisting of two polarized plastic discs.

FIGURE 2 shows the overall block diagram of the preferred control system wherein the crystal puller and the crucible lifter drive means are both adjusted according to the output of the radiation detector 30. Radiation from the melt surface about 0.04 to 0.21 inch from the edge of the growing crystal is sensed using, a field of view, such as at A in FIGURE 3, of the radiation detector 30. The output of the radiation detector 30 is proportional to the sensed radiation. This output is generally of a low value so that amplifiers 50 and 52 are required for

amplifying the signal. The amplified signal is then applied, respectively, to the power controllers 54 and 56 for the crystal puller drive and the crucible lifter drive. The power controllers 54 and 56 control or adjust the crystal puller drive 58 and crucible lifter drive 60.

The power controller is an instrument which provides a means for controlling the RMS value of an AC line voltage applied to a load in response to a DC control signal. One type of preferred power controller utilizes silicon controlled rectifiers which are pulsed into conduction by a magnetic amplifier. The RMS voltage delivered to a load is proportional to the period of time that the silicon control rectifier fires and conducts during each voltage cycle, which in turn is proportional to the magnitude of the control signal. The magnetic amplifier which generates gating pulses employs a saturable-core toroid transformer. These transformer-cores have a hysteresis curve which is essentially square, and will oppose a change in the polarity of their residual magnetism until the polarizing currents obtain a certain time-magnitude. At this point the polarity of the cores will instantaneously flip, causing a drop in the initially high impedance presented in the repolarizing current. The magnitude of setting-current required to flip a core is proportional to the flux density of its residual magnetism, which in turn, is proportional to the magnitude of the current used to drive the core back to its initial reset (state). Each core is set during the positive half-cycle of the line current and reset during the negative half-cycle. The reset-flux density may be varied to cause the silicon controlled rectifier to be fired at any given angle within its half-cycle of line voltage. In this manner the RMS voltage delivered to a load may be varied from 0 to approximately the full line value.

The crucible rotation drive 62 can additionally be adjusted by another power controller for additional control of the crystal growth. The effect of crucible rotation is that a decreased crucible rotation rate effectively increases the temperature of the melt. When the crystal diameter begins to decrease, an increase in crucible rotation rate decreases the temperature and thereby restores the crystal diameter to its desired value. The crystal rotation drive 64 is maintained at a constant rotation rate.

The use of the adjustment on the crucible lift in addition to the adjustment on the crystal puller means allows the melt level to be kept constant and thereby reduces the variation in sensitivity and thermal conditions that comes about by the movement of the melt level in relation to the heater. The maintenance of a constant melt level is important because the lowering of the melt level will give an erroneous increase in the output of detector 30 which thereby results in a decrease in the crystal diameter. The reverse is true if the melt level rises. The relationship among the parameters affecting the melt level can be derived. Thus:

$$f = Se \left(1 + \frac{r^2}{R - r^2} \right) - Ce$$

where:

f =crystal growth rate,
 Se =seed elevation rate,
 r =crystal diameter,
 R =crucible diameter,
 Ce =crucible elevation rate.

It can be seen from the above that when

$$\frac{Ser^2}{R^2 - r^2} = Ce, f = Se$$

and the melt level remains constant. It can also be seen from the above that when R decreases rapidly; that is, when the crystal is being pulled from the curved bottom of the crucible, the melt level drops rapidly. One would

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expect the diameter to decrease at this point because of the sight angle. Should the crucible lifter drive not be used the radiation detector would periodically have to be refocused and repositioned.

The system allows the growth of unlimited types of crystals in addition to the silicon single crystal used in the above description to illustrate the invention. Other suitable crystals are germanium, cuprous chloride, cuprous bromide, gallium arsenide, etc. Further, dopants may be added by any conventional means to the bell jar 22 in the case of semiconductor crystals and the crystals are grown doped.

From the foregoing description and explanation, it will be seen that the automatic control system of the present invention is a relatively simple one for providing an elongated crystal of a controlled diameter whether it be a uniform diameter or a varying diameter over the crystal's length. Where a uniform diameter control is desired, crystal to crystal reproducibility has been measured with a micrometer over many runs to give an average deviation from the mean crystal diameter of 0.005 to 0.01 inch. This type of accurate control has been wholly impossible to obtain where this control system was not used regardless of the skill of the operator controlling the crystal growth.

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. A system for automatically growing an elongated, controlled diameter crystal from a melt of material comprising:

a radiation detector for sensing radiation derived and propagating from the upper surface of said melt and providing an output proportional to the amount of radiation sensed;

means for positioning said detector so as to place its field of view on the surface of the melt adjacent to the crystal being grown;

crystal pulling means for raising the said crystal as it is being grown;

a container for holding said melt;

a container lifting means for raising the said container as the said crystal is being grown; and

means for continuously adjusting said pulling means and said lifting means in response to said output from said detector to control the diameter of said crystal.

2. The system of claim 1 wherein there is provided a means for moving the field of view of the said detector to set the diameter of the said crystal.

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3. The system of claim 1 wherein there is provided a view port through which said detector views the said melt; and

a means for providing a gas shield over the surface of said view port on the side of said melt to maintain the said view port free of deposit.

4. A system for automatically growing an elongated, uniform diameter silicon crystal from a melt of silicon comprising:

a radiation detector for sensing radiation derived and propagating from the upper surface of said melt and providing an output proportional to the amount of radiation sensed;

said detector having a spectral band sensitivity of about 0.65 to 0.90 micron;

means for positioning said detector so as to place its field of view on the surface of the melt adjacent to the crystal being grown;

crystal pulling means for raising the said crystal as it is being grown;

a crucible for holding said melt;

a crucible lifting means for raising the said crucible as the said crystal is being grown; and

means for continuously adjusting said pulling means and said lifting means in response to said output from said detector to control the diameter of said crystal.

5. The system of claim 1 wherein there is provided a means for moving the field of view of the said detector to set the said uniform diameter of said crystal.

6. The system of claim 4 wherein there is provided means for rotating said crucible lifting means as the said crystal is being grown; and

means for adjusting the rate of rotation of said means for rotating.

7. The system of claim 4 wherein:

the said field of view of said detector being circular and having a diameter of about 0.1 inch; and
said field of view being located about 0.04 to 0.21 inch from the growing crystal.

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WALTER STOLWEIN, Primary Examiner

U.S. Cl. X.R.

23—273; 250—218, 222