

[54] **AUTOMATIC MELT LEVEL CONTROL FOR GROWTH OF SEMICONDUCTOR CRYSTALS**

[75] Inventors: **Donald R. Clement**, Scottsdale; **Larry D. Mason**, Phoenix; **Carl A. Helber**, Scottsdale, all of Ariz.

[73] Assignee: **Motorola, Inc.**, Chicago, Ill.

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[58] Field of Search **250/222, 221, 215, 574, 250/577; 23/301 SP, 273 SP; 356/159, 161**

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Primary Examiner—Walter Stolwein

Attorney, Agent, or Firm—Vincent J. Rauner; Henry T. Olsen

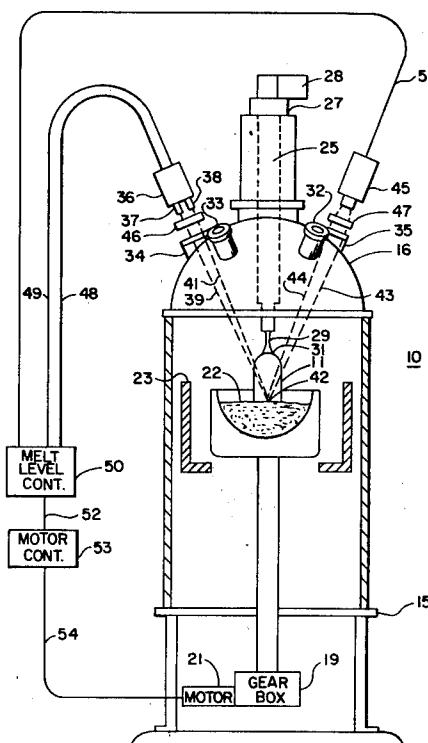
[57] **ABSTRACT**

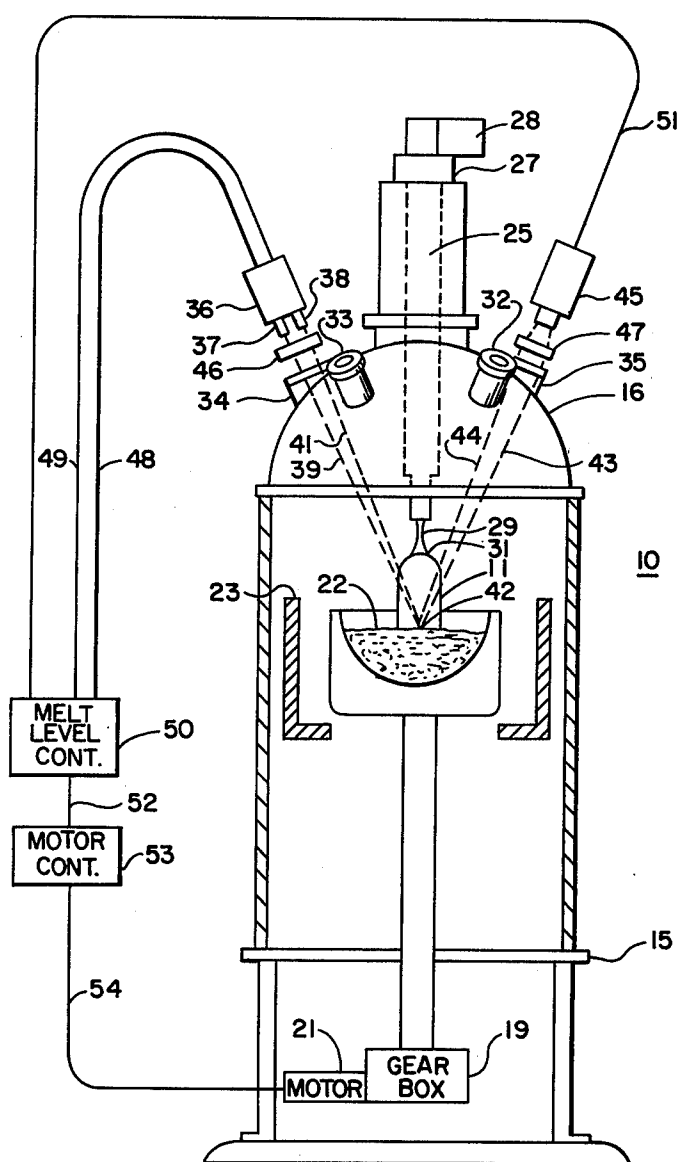
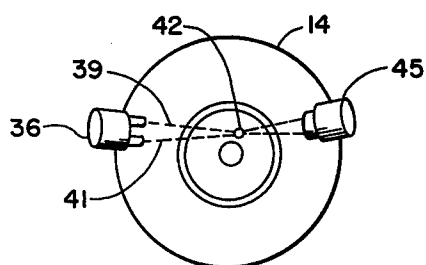
Apparatus for controlling the melt level in a Czochralski crystal pulling method is disclosed. The melt level control has a feedback loop including level sensing means which controls a lift motor for moving the melt containing crucible up or down as called for. The melt level is sensed by alternately transmitting two pulsed beams, or rays, of narrow band visible red light radiation to the melt level surface and measuring the radiation level in the reflected pulse rays after transmission through a lens system. When the melt level is correct the magnitudes of the reflected pulses are equal and no control signal results. When the melt level falls, the magnitudes of the reflected pulses change and a difference signal in one direction is generated causing the crucible to rise.

When the melt level rises, the magnitudes of the reflected pulses change and a difference signal in the opposite direction is generated causing the crucible to fall.

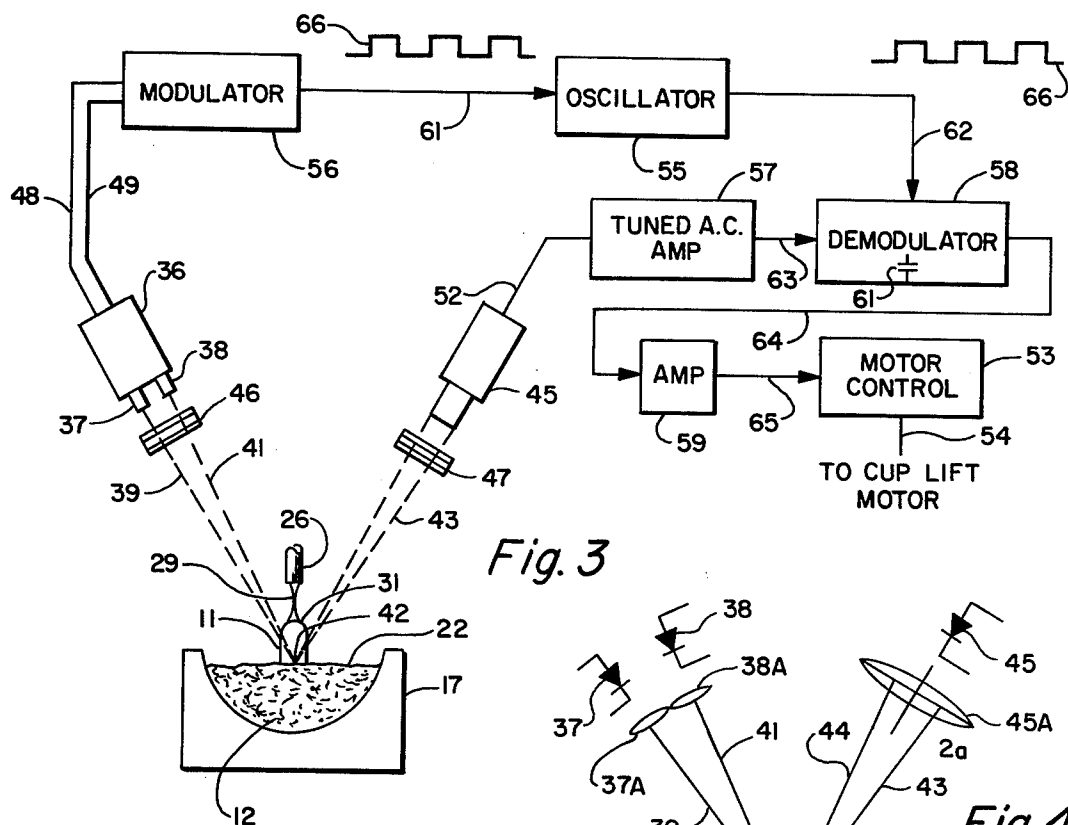
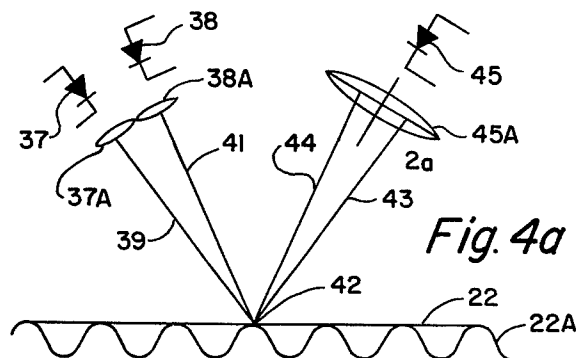
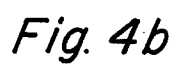
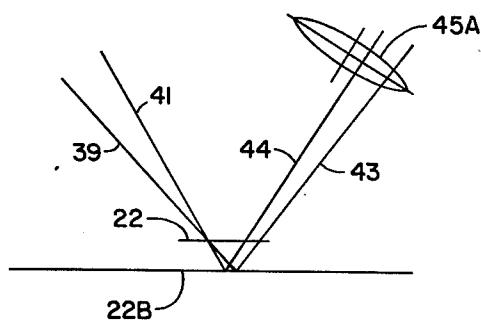
The red light radiation preferably has a wavelength of 6500 A plus or minus 50 A.

16 Claims, 6 Drawing Figures





SHEET 2 OF 2



AUTOMATIC MELT LEVEL CONTROL FOR GROWTH OF SEMICONDUCTOR CRYSTALS

BACKGROUND OF THE INVENTION

This application is related to application Ser. No. 494,438, filed Aug. 5, 1974, in the names of Donald R. Clement, Larry D. Mason and Carl A. Helber, entitled Automatic Crystal Diameter Control For Growth of Semiconductor Crystals and assigned to the same assignee as the subject application.

This invention relates to apparatus for growing semiconductor crystals, such as, for example, silicon or germanium crystals, by the Czochralski method, more particularly to apparatus for maintaining the melt level at a constant height while the crystal is being pulled, and it is an object of the invention to provide improved apparatus of this nature.

The Czochralski method of crystal growing is well known and various schemes are available in the prior art for maintaining the melt level constant, or essentially so, during the crystal pulling, or growing, process. Such melt level control schemes, whether of the open loop, or closed loop variety, have not been satisfactory because of their complexity and their inability to produce crystals of a quality desired.

It is a further object of the invention to provide an improved melt level control of the character indicated which is simple in form, accurate in operation and achieves higher quality crystals for example crystals having better thermal stability and more consistent and repeatable crystal diameter.

SUMMARY OF THE INVENTION

According to one form of the invention, there is provided apparatus for pulling solid crystals from a melt wherein the level of said melt is maintained constant during the time that the crystal is being pulled comprising: a container for said melt; motor means for raising and lowering said container, source means for transmitting, at one angle to the vertical, a radiation beam to the level surface of said melt; sensor means for receiving the reflection of said radiation beam; said sensor means being disposed at the same angle to the vertical as said source beam; said sensor means including means for detecting changes in said reflected radiation beams caused by corresponding changes in said melt level; and means controlled by said detecting means for effecting energization of said motor means to raise and lower, respectively, said container.

In carrying out the invention according to another form, there is provided apparatus for pulling solid crystals from a melt wherein the level of said melt is maintained constant during the time that the crystal is being pulled comprising: a container for said melt; motor means for raising and lowering said container; first source means for transmitting, at one angle to the vertical, a first radiation beam to the level surface of said melt; second source means for transmitting, at another angle to the vertical, a second radiation beam to the level of said melt; sensor means for receiving the reflections of said first and said second radiation beams; said sensor means being disposed at an angle to the vertical to encompass the reflections of said first and said second radiation beams; said sensor means including means responsive to changes in said first and second reflected radiation beams caused by corresponding changes in said melt level; and means controlled by said

responsive means for effecting energization of said motor means to raise and lower, respectively, said container.

In either form of the invention narrow band visible red radiation is preferred. Such radiation being of the wavelength of approximately $6500 \text{ \AA} \pm 50 \text{ \AA}$.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the invention reference should be had to the drawings in which FIG. 1 is a somewhat diagrammatic representation, partially in section, of apparatus and system embodying the invention.

FIG. 2 is a top view of the apparatus shown in FIG. 1;

FIG. 3 is a circuit diagram and schematic representation of the apparatus according to the invention and

FIGS. 4A, 4B and 4C are diagrammatic representations showing three stages in the operation of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings there is shown apparatus 10 for pulling a crystal 11 from a melt 12. For example, the crystal may be silicon, germanium or other.

The apparatus 10 may comprise a more or less cylindrical chamber 13 of usual form and construction including a main body portion 14, a base 15 and a covering dome 16. The interior of the chamber 13 may be filled with any desired atmosphere. Interiorly of the chamber 13 there is a crucible 17 made of quartz, for example, supported on a shaft 18 which projects through the base 15 and is connected to a gear box 19. The gear box is associated with a drive motor 21 whereby the crucible 17, through the shaft 18, is rotated and the height of the crucible 17 may be raised or lowered so as to maintain the surface 22 of the melt constant throughout the crystal pulling operation as will be more fully explained.

Surrounding the crucible 17 is a heater 23 which conveniently may be electrical and of any well known form. Atop the dome 16 there is a shaft guide member 24 through which projects the shaft 25 for supporting the seed crystal 26. The shaft 25 is attached to a gear box 27 which is associated with a seed pull motor 28. The motor 28, through the gear box 27, acts to lift or pull the shaft 25 whereby the seed crystal 26 is pulled away from the surface 22 of melt 12 and, in so doing, forms a necked-down portion 29, a shoulder 31 and ultimately the crystal 11 at its final diameter.

Also associated with the dome 16 are observation windows 32 and 33.

Directly opposite each other but displaced laterally from a diametrical line are two windows 34 and 35 through which visible red radiation is transmitted and received respectively. Red radiation is generated in the transmitter or source 36 which comprises two red sources 37 and 38 from which red radiation beams 39 and 41 are transmitted and aimed at a spot 42 on the surface 22 of the melt 12. Beams 43 and 44 of red radiation reflected, respectively, from beams 39 and 41 are transmitted through window 35 to the sensor, or receiver, 45. Visible red radiation is used in order to distinguish the transmitted light from the infrared and other radiation coming from the hot silicon surface.

The transmitted beams 39 and 41 pass through a water cooled infrared filter 46 and the reflected beams 43 and 44 pass through a water cooled infrared filter 47. The red sources in the transmitter 37 are energized through conductors 48 and 49 extending from the melt level control 50 and the pick up signals received by the sensor 45 are transmitted by way of conductor 51 to the melt level control 50. The melt level control transmits the appropriate signal over conductor 52 to the motor control 53 from which control signals pass over conductor 54 to the motor 21. The latter control signals effect energization of the motor so that it causes the crucible 17 to be raised or lowered as will be more fully explained.

Referring to FIG. 2 there is shown in a top view, somewhat diagrammatically, the wall 14 of the chamber 13 the red transmitter 36 and the red sensor or receiver 45. The transmitted rays 39 and 41 are shown directed to the spot 42 and the reflected rays 43 and 44 are shown received by the sensor 45.

Referring to FIGS. 3, 4A, 4B and 4C, the additional structure and operation of the invention may be understood. In these figures the same reference characters are used for the corresponding parts.

The melt level control 50 as shown in FIG. 1 comprises the oscillator 55, the modulator 56, tuned AC amplifier 57, the demodulator 58, the amplifier 59 and the interconnecting conductors 61, 62, 63, 64 and 65.

The oscillator 55 generates a relatively high frequency square wave signal for example a signal of 1KHz which is transmitted over conductor 61 to modulator 56. The modulator 56 is essentially a high frequency switch which first energizes one red source 37 and then the other red source 38. That is to say the red sources 37 and 38 are alternately on and off. In effect the high state of the wave 66 may be considered to energize the source 37 and the low state of the same wave may be considered as energizing the other infrared source 38. The red sources 37 and 38 may be for example light emitting diodes shown as 37 and 38 in FIG. 4A. The source 37, as shown in FIG. 4A may include a lens 37A for directing the beam 39 to the spot 42. Similarly the source 38 may include a lens 38A for directing the beam 41 to the spot 42. The transmitted beam 39 reflects from spot 42 as reflected beam 43 and the transmitted beam 41 reflects from the spot 42 as reflected beam 44 as has been described in connection with FIG. 1.

The sensor 45 may be any well known sensitive device such for example as a photodiode, or photocell shown as 45 in FIG. 4A. The sensor 45 includes a lens 45A which has sufficient diameter to pick up both the reflected rays 43 and 44.

The energy in beams 43 and 44 after transmission through lens 45A and impinging upon the photosensitive element 45 is amplified in the tuned AC amplifier 57 and conducted over conductor 63 to demodulator 58 which may be of conventional form and develops a signal or voltage level, for example, in capacitor 67. When the level of the melt 22 is correct the charge, or voltage, on capacitor 67 will have a particular value which is representative of the proper value of melt level whereupon no signal is transmitted over conductor 54 and the motor 21 remains stationary. As the melt level increases, for example, the charge on capacitor 67 will increase thereby causing a signal to be transmitted over conductor 64 to amplifier 59 and over conductor 65 to

motor control 53 whereby the motor 21 is caused to lower the crucible 17 and thus the melt level value. If, on the other hand, the melt level should decrease the charge on capacitor 67 will decrease whereby a decreased, or different, signal is conducted over conductor 64 to amplifier 59 and to the motor control 53 thereby causing the motor to turn in the reverse direction to increase the height of the crucible 17 and thus the height of the melt level.

In FIG. 4A the melt level 22 is shown at the desired position or value but the surface of the melt is shown as consisting of a series of sine waves or ripples 22A. Experience shows that in crystal pulling apparatus of the nature under consideration, the surface of the liquid silicon, germanium, or the like, has ripples moving through it virtually all of the time. These ripples are of relatively low frequency for example 5 cycles per second but nevertheless they enter into the consideration going to control of the melt level. The frequency generated by oscillator 55 of 1KHz is sufficiently high that the ripples 22A are insignificant in the operation of the apparatus. There will be sufficient number of cycles in the transmission of the infrared radiation so that it can be considered that the rays will impinge at the same spot on the ripples as they move. This can be the top but choosing this spot for explanation is a matter of convenience inasmuch as the invention may be explained by having the spot 42 at the trough of the ripple or along the sides.

When the level 22 is at the proper point, as shown in FIG. 4A, the reflected ray 44 is on one side of the geometrical center of the lens 45A and the reflected ray 43 is on the opposite side of the geometrical center of the lens 45A by the same amount. Thus the radiant energy falling on the sensor 45 is equal insofar as rays 43 and 44 are concerned. The square wave signal 66 generated by oscillator 55, in passing over conductor 62 to the modulator 58, causes the energy received by sensor 45 in response to the infrared radiation beam 39 for example to add to the charge in capacitor 67 and on the next half cycle, when the beam 41 is energized, the demodulator causes the energy picked up to be subtracted from the charge in capacitor 67. Thus the capacitor 67 received alternately charging and discharging pulses depending on the half waves of the oscillator 55. Hence, if the melt level 22 is at the point desired, the alternate pulses of charge received by the capacitor 67 are equal in value and thus the average value of the charge on the capacitor 67 remains the same. Consequently no signal is generated by the motor control 53 and the crucible 17 remains at its proper level.

It may be observed that the angle of ray 44 with respect to the vertical is the same as the angle of the transmitted ray 41. Correspondingly the angle of reflected ray 43 is at the same angle to the vertical as the transmitted ray 39. The angle between rays 41 and 44 is approximately 45° and the angle between rays 39 and 43 is slightly larger because of the displacement between the sensors 37 and 38 but the difference in angle is small, so that for all practical purposes it may be considered that the angle between rays 39 and 43 is also 45°. This is by way of example only as will be understood since the angles may be made of any value desired to meet the particular conditions of operation for a particular piece of apparatus.

Referring to FIG. 4B there is shown a condition wherein the level of the melt in crucible 17 has changed

from the correct value 22 to a lower value 22B. Under this condition the transmitted ray 41 reflecting as reflected ray 44 impinges upon the lens 45A adjacent the center thereof although on the opposite side of the center as compared with FIG. 4A. The transmitted ray 39 reflects as ray 43 and impinges upon the lens 45 adjacent the right hand edge thereof. Under this condition it will be evident that the amount of energy in reflected ray 43 impinging upon the sensor 45 will be substantially less than that coming from the reflected ray 44.

In the case of FIG. 4B the pulse of charge added to capacitor 67, as caused by the reflected ray 44 is greater than the charge added to capacitor 67 by virtue of the reflected beam 43. Over a period of several cycles the charge accumulation in the capacitor 67 is positive or increasing because the positive pulse added thereto exceeds the negative pulse. Thus, a positive signal is generated by the demodulator 58 and, after amplification by the amplifier 59, is transmitted to the motor control 53 and ultimately to the motor 21. This causes the crucible 17 to be lifted to bring the level 22B up to the level 22.

In FIG. 4C the condition is illustrated wherein the original level 22 is shown at the proper point but the melt level in the crucible has risen to a level 22C which is higher than that desired. The transmitted ray 39 impinging on melt level surface 22C, reflects as ray 43 and impinges on the lens 45A adjacent its center. Similarly the transmitted ray 41 impinging on the melt level surface 22C reflects as ray 44 and impinges on the lens 45A adjacent its left hand edge. In the sequence of operations as described for the preceding FIGS. 4A and 4B and now applicable to FIG. 4C, it will be observed that the reflected ray 44 being adjacent the outer edge of lens 45A causes the sensor 45 to pick up less radiant energy, and causes a smaller pulse of charge to be added to that in capacitor 67. The reflected ray 43 coming from transmitted ray 39 and impinging upon lens 45 adjacent its center causes a larger pulse of charge to be subtracted from the charge in capacitor 67. Thus with each complete cycle of both beams 39 and 41 being energized the charge in capacitor 67 decreases because a larger pulse of charge is subtracted on each half cycle than is added to it on the corresponding opposite half cycle. The average net charge on capacitor decreasing, a decreased voltage signal is transmitted over conductor 64 to amplifier 59 to motor control 53 and thus ultimately to the motor 21 over conductor 54. The decreased signal causes the motor to run in the reverse direction, thereby lowering the crucible 17 and the melt level 22C until it reaches the melt level 22, the desired value. At this point the elements of charge added to and subtracted from the charge on capacitor 67 on alternate half cycles of the oscillator wave are the same.

The system described is a feedback or closed loop system in that the melt level control is automatically adjusted by the motor 21 and its control 53 in response to melt level whenever the melt level changes.

The light emitting diodes 37 and 38 may emit red light in the region of 5000 A units to 10,000 A, but for preferred results the wavelength of 6500 A is used. The filter 46 is a very narrow bandpass filter designed to pass the frequency of 6500 A units with a band width of plus or minus 50 A. The filter 46 may comprise two relatively thin quartz plates with a centimeter of water in between. The edges of the quartz plates of course are

sealed to retain the water therein. Such a quartz filter reduces the long wave infrared radiation to protect itself and the sensing apparatus from the heat which would be generated if all of the longer wave infrared radiation were transmitted.

The infrared filter 47 is of the same construction as 46.

The photocell or red sensor 45 can be of any well known form for this purpose. Two photocells in place of one may be used instead of one in the same circuit arrangement but such a circuit tends to have higher noise level response. Improved results are obtained by using a single photocell and improved electronic circuitry.

What is claimed is:

1. Apparatus for pulling solid crystals from a melt wherein the level of said melt is maintained constant during the time that the crystal is being pulled comprising:

- a container for said melt;
- motor means for raising and lowering said container;
- source means for transmitting, at one angle to the vertical, a red radiation beam having a wavelength of approximately 6500A to the level surface of said melt;
- sensor means for receiving the reflection of said radiation beam;
- said sensor means being disposed at the same angle to the vertical as said source beam;
- said sensor means including means for detecting changes in said reflected radiation beams caused by corresponding changes in said melt level; and
- means controlled by said detecting means for effecting energization of said motor means to raise and lower, respectively, said container.

2. Apparatus according to claim 1 wherein the angle between said source beam and said reflected beam is approximately 45°.

3. Apparatus according to claim 2 wherein one of said source means and said sensor means includes a narrow bandpass red filter.

4. Apparatus according to claim 2 wherein each of said source means and said sensor means includes a narrow bandpass red filter.

5. Apparatus according to claim 3 wherein said bandpass filter transmits at approximately 6500 A $\pm$ 50 A.

6. Apparatus for pulling solid crystals from a melt wherein the level of said melt is maintained constant during the time that the crystal is being pulled comprising:

- a container for said melt;
- motor means for raising and lowering said container;
- first source means for transmitting, at one angle to the vertical, a first radiation beam to the level surface of said melt;
- second source means for transmitting, at another angle to the vertical, a second radiation beam to the level of said melt;
- sensor means for receiving the reflections of said first and said second radiation beams;
- said sensor means being disposed at an angle to the vertical to encompass the reflections of said first and said second radiation beams;
- said sensor means including means responsive to changes in said first and second reflected radiation beams caused by corresponding changes in said melt level; and

means controlled by said responsive means for effecting energization of said motor means to raise and lower, respectively, said container.

7. Apparatus according to claim 6 wherein said radiation is red light radiation.

8. Apparatus according to claim 7 wherein said red radiation has a wavelength of approximately 6500 Å.

9. Apparatus according to claim 7 wherein one of said first and second source means includes a narrow bandpass red filter.

10. Apparatus according to claim 7 wherein each of said source means and said sensor means includes a narrow bandpass red filter.

11. Apparatus according to claim 9 wherein said bandpass filters transmit at approximately 6500 Å units ± 50 Å.

12. Apparatus according to claim 7 wherein said sensor means is responsive to the sum of the reflected radiation received from said first and said second radiation beams.

13. Apparatus according to claim 6 wherein the angle between said first and said second source beams and said reflected beams is approximately 45°.

14. Apparatus for pulling solid crystals from a melt wherein the level of said melt is maintained constant during the time that the crystal is being pulled comprising:

a container for said melt;

motor means for raising and lowering said container;

first red source means for transmitting, at one angle to the vertical, a first radiation beam to the level surface of said melt;

second red source means for transmitting, at another angle to the vertical, a second radiation beam to

the level surface of said melt;

sensor means for receiving the sum of the reflections of said first and said second radiation beams;

said sensor means being disposed at an angle to the vertical to encompass the reflections of said first and said second radiation beams;

means for alternately energizing said first and said second source means at a high frequency rate;

means for focusing each of said first and said second radiation beams on the same spot at a designated melt level;

said sensor means including means responsive to changes in said first and said second reflected radiation beams caused by corresponding changes in said melt level; and

means controlled by said responsive means for effecting energization of said motor means to raise and lower, respectively, said container.

15. Apparatus according to claim 12 wherein said sensor means includes focusing means whereby the reflected beam from one of said first and said second radiation beams is greater in magnitude than that of said another reflected beam when said melt level is below a predetermined value, and whereby the reflected beam from said one of said first and said second radiation beams is lesser in magnitude than that of said another reflected beam when said melt level is above said predetermined value.

16. Apparatus according to claim 15 including a high frequency oscillator for energizing said first and said second radiation sources and for controlling the demodulation of the signals received by said sensor means.

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