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BI-DIRECTIONAL HEATING OF A SILICON CHARGE

Abstract

Bi-directional heating of a charge of solid silicon in a crucible assembly of an ingot puller apparatus is disclosed. The ingot puller apparatus may include an elliptical reflector disposed above the charge during meltdown. In some embodiments, an upper heater is disposed above the charge and heat from the upper heater is reflected down toward the charge by the elliptical reflector.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application claims the benefit of U.S. Provisional Patent Application No. 63/551,147, filed Feb. 8, 2024, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The field of the disclosure relates to bi-directional heating of a charge of solid silicon in a crucible assembly of an ingot puller apparatus.

BACKGROUND

[0003] Single crystal silicon, which is the starting material for most processes for the fabrication of semiconductor electronic components, is commonly prepared by the so-called Czochralski ("Cz") method. According to the Czochralski method, solid polycrystalline silicon ("polysilicon") is charged to a crucible and melted. A seed crystal is brought into contact with the molten silicon and a single crystal ingot is grown by slow extraction.

[0004] Conventional methods for melting the charge of solid silicon involve bringing the crucible into proximity with the bottom heater and powering the bottom heater and side heater to melt the charge. Melting occurs by heating through the susceptor and crucible. Heat transfer occurs by radiation from the bottom and side heaters. This radiation is incident on the susceptor which supports the crucible. The heat conducts through the crucible and is transferred across a small gap into the crucible. Energy transfers through the crucible wall by conduction or radiation. Depending on the transparency of the crucible, some energy is scattered on the outer surface and reflected back into the susceptor. Once the energy passes through the crucible, it becomes incident on the solid silicon and raises the temperature and converts the solid polysilicon into liquid silicon through melting.

[0005] The arrangement of materials and surfaces in the ingot puller apparatus are characterized by built in inefficiencies and heat losses which are compensated by increasing the power of the heater(s) to effect a relatively quick meltdown. This increase in power promotes reaction between graphite and silica surfaces, resulting in higher erosion rates of the materials. Increased temperatures also cause higher defectivity in the crucible and causes bubbles to expand. Higher heating temperatures cause non-uniform heating of the crucible sidewall which affects the surface devitrification on the crucible and increases silicon defectivity. This defectivity in the silicon is manifested through increased loss of zero dislocation structure during the ingot growth cycle and increased air pocket formation.

[0006] A need exists for ingot puller apparatus and methods for producing a single crystal silicon ingot which increase the efficiency at which the silicon charge is melted.

[0007] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

SUMMARY

[0008] One aspect of the present disclosure is directed to an ingot puller apparatus for manufacturing a single crystal silicon ingot. The ingot puller apparatus includes a crucible assembly for holding a silicon melt. A crystal puller housing defines a growth chamber for pulling a silicon ingot from the silicon melt. The crucible assembly is disposed within the growth chamber. A side heater is disposed radially outward to the crucible assembly. An elliptical reflector is disposed above the crucible assembly. The elliptical reflector defines a reflector chamber. An upper heater is disposed within the reflector chamber.

[0009] Another aspect of the present disclosure is directed to an ingot puller apparatus for manufacturing a single crystal silicon ingot. The ingot puller apparatus includes a crucible assembly for holding a silicon melt. A crystal puller housing defines a growth chamber for pulling a silicon ingot from the silicon melt. The crucible assembly is disposed within the growth chamber. A single elliptical reflector is disposed above the crucible assembly. The single elliptical reflector

defines a reflector chamber. An upper heater is disposed within the reflector chamber.
[0010] Yet another aspect of the present disclosure is directed to a method for preparing a single crystal silicon ingot in an ingot puller apparatus. The ingot puller apparatus includes a crucible assembly for holding a melt of silicon, a growth chamber for pulling a silicon ingot from the melt along a pull axis, a side heater disposed radially outward to the crucible assembly, and a pull mechanism for raising and lowering the crucible assembly during crystal growth relative to the pull axis. A charge of solid silicon is added to the crucible assembly. An elliptical reflector is connected to the pull mechanism. The pull mechanism is operated to lower the elliptical reflector toward the charge of solid silicon. An upper heater is powered to direct radiant heat toward the elliptical reflector. The elliptical reflector reflects radiant heat into the charge of solid silicon to melt the silicon charge and form a silicon melt. The elliptical reflector is removed from the ingot puller apparatus. A seed crystal is connected to the pull mechanism. The pull mechanism is operated to lower the seed crystal to contact the silicon melt. The pull mechanism is operated to raise the seed crystal to cause a silicon ingot to be withdrawn from the melt.
[0011] Yet a further aspect of the present disclosure is directed to an ingot puller apparatus for manufacturing a single crystal silicon ingot. The ingot puller apparatus includes a crucible assembly for holding a silicon melt. A crystal puller housing defines a growth chamber for pulling a silicon ingot from the silicon melt. The crucible assembly is disposed within the growth chamber. A side heater is disposed radially outward to the crucible assembly. An elliptical reflector is disposed above the crucible assembly. The elliptical reflector defines a reflector chamber. The elliptical reflector is torus-shaped and has a central opening.
[0012] Various refinements exist of the features noted in relation to the above-mentioned aspects of the present disclosure. Further features may also be incorporated in the above-mentioned aspects of the present disclosure as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to any of the illustrated embodiments of the present disclosure may be incorporated into any of the above-described aspects of the present disclosure, alone or in any combination.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0013] FIG. **1** is a cross-section view of an ingot puller apparatus having a crucible with a silicon charge therein;
[0014] FIG. **2** is a cross-section view of the ingot puller apparatus with an elliptical reflector and upper heater connected to the pull mechanism;
[0015] FIG. **3** is a cross-section view of the ingot puller apparatus after melt-down and before contacting the melt with a seed crystal;
[0016] FIG. **4** is a cross-section view of the ingot puller apparatus during ingot growth;
[0017] FIG. **5** is a cross-section view of the ingot puller apparatus with the ingot being fully formed;
[0018] FIG. **6** includes schematic views of the ingot puller apparatus during meltdown; and
[0019] FIG. **7** is a cross-section view of another embodiment of an ingot puller apparatus with a torus-shaped elliptical reflector and upper heater.
[0020] Corresponding reference characters indicate corresponding parts throughout the drawings.
DETAILED DESCRIPTION
[0021] Provisions of the present disclosure relate to ingot puller apparatus that include an elliptical reflector disposed above the crucible assembly for meltdown of solid silicon to prepare a silicon melt used during the Czochralski process. An ingot puller apparatus (or more simply “ingot puller”) is indicated generally at “**100**” in FIGS. **1-5**. The ingot puller apparatus **100** includes a crucible

assembly **102** for holding a melt **104** (FIG. **3**) of semiconductor or solar-grade material, such as silicon, supported by a susceptor **106**. The ingot puller apparatus **100** includes a crystal puller housing **108** that defines a growth chamber **152** for pulling a silicon ingot **113** (FIG. **4**) from the melt **104** along a pull axis A.

[0022] The crucible assembly **102** includes a floor **129** and a sidewall **131** that extends upward from the floor **129**. The sidewall **131** is generally vertical. The floor **129** includes the curved portion of the crucible assembly **102** that extends below the sidewall **131**. Within the crucible assembly **102** is a silicon melt **104** having a melt surface **111** (i.e., melt-ingot interface).

[0023] The susceptor **106** is supported by a shaft **105**. The susceptor **106**, crucible assembly **102**, shaft **105** and ingot **113** (FIG. **4**) have a common longitudinal axis A or "pull axis" A.

[0024] The ingot puller apparatus **100** includes a pull mechanism **114** for growing and pulling an ingot **113** from the melt **104**. Pull mechanism **114** includes a pulling cable **118**, a seed holder or chuck. One end of the pulling cable **118** is connected to a pulley (not shown) or a drum (not shown), or any other suitable type of lifting mechanism, for example, a shaft, and the other end is connected to the chuck **120**. For ingot growth, a seed crystal **122** is connected to the chuck **120** and the seed crystal **122** is lowered to contact the melt **104**. The pull mechanism **114** is operated to cause the seed crystal **122** to rise. This causes a single crystal ingot **113** (FIG. **4**) to be pulled from the melt **104**.

[0025] During heating and crystal pulling, a crucible drive unit **107** (e.g., a motor) rotates the crucible assembly **102** and susceptor **106**. A lift mechanism **112** raises and lowers the crucible assembly **102** along the pull axis A during the growth process. For example, as shown in FIG. **1**, the crucible assembly **102** may be at a lowest position (near the bottom heater **126**) in which a charge **117** (FIG. **1**) of solid polycrystalline silicon previously added to the crucible assembly **102** is melted. After meltdown, crystal growth commences by contacting the melt **104** (FIG. **3**) with the seed crystal **122** and lifting the seed crystal **122** by the pull mechanism **114**. The crucible assembly **102** may be raised a distance from its lowest position before the melt **104** is contacted with the seed crystal **122** (i.e., raised to a "seed-dip position"). As the ingot **113** grows, the silicon melt **104** is consumed and the height of the melt **104** in the crucible assembly **102** decreases. The crucible assembly **102** and susceptor **106** may be raised to maintain the melt surface **111** at or near the same position relative to the ingot puller apparatus **100**.

[0026] A crystal drive unit (not shown) may also rotate the pulling cable **118** and ingot **113** in a direction opposite the direction in which the crucible drive unit **107** rotates the crucible assembly **102** (e.g., counter-rotation). In embodiments using iso-rotation, the crystal drive unit rotates the pulling cable **118** in the same direction in which crucible drive unit **107** rotates the crucible assembly **102**. In addition, the crystal drive unit **107** raises and lowers the ingot **113** relative to the melt surface **111** as desired during the growth process.

[0027] The ingot puller apparatus **100** may include an inert gas system to introduce and withdraw an inert gas such as argon from the growth chamber **152**. The ingot puller apparatus **100** may also include a dopant feed system (not shown) for introducing dopant into the melt **104**.

[0028] According to the Czochralski single crystal growth process, a charge **117** (FIG. **1**) of polycrystalline solid silicon, or polysilicon, is charged to the crucible assembly **102**. Solid silicon that is used to form the charge **117** may be granular, chunk, chip, or a combination of thereof. The semiconductor or solar-grade material that is introduced into the crucible assembly is melted by heat provided from one or more heaters. The ingot puller apparatus **100** includes bottom insulation **110** and side insulation **124** to retain heat in the puller apparatus **100**. In the illustrated embodiment, the ingot puller apparatus **100** includes a bottom heater **126** disposed below the crucible assembly **102** (i.e., below the floor **129**). The crucible assembly **102** may be moved to be in relatively close proximity to the bottom heater **126** to melt the polycrystalline solid charge **117** in the crucible assembly **102**.

[0029] To form the ingot, the seed crystal **122** is contacted with the surface **111** (FIG. **3**) of the melt

104. The pull mechanism **114** is operated to pull the seed crystal **122** from the melt **104**. Referring now to FIG. **4**, the ingot **113** includes a crown portion **142** in which the ingot transitions and tapers outward from the seed crystal **122** to reach a target diameter. The ingot **113** includes a constant diameter portion **145** or cylindrical “main body” of the crystal which is grown by increasing the pull rate. The main body **145** of the ingot **113** has a relatively constant diameter. The ingot **113** includes a tail or end-cone **149** (FIG. **5**) in which the ingot tapers in diameter after the main body **145**. When the diameter becomes small enough, the ingot **113** is then separated from the melt **104**.

[0030] The ingot puller apparatus **100** includes a side heater **135** and a susceptor **106** that encircles the crucible assembly **102** to maintain the temperature of the melt **104** during crystal growth. The side heater **135** is disposed radially outward to the crucible assembly sidewall **131** as the crucible assembly **102** travels up and down the pull axis A (e.g., from the lowest position to the terminal position). The side heater **135** and bottom heater **126** may be any type of heater that allows the side heater **135** and bottom heater **126** to operate as described herein. In some embodiments, the heaters **135**, **126** are electrical resistance heaters. The side heater **135** and bottom heater **126** may be controlled by a control system (not shown) so that the temperature of the melt **104** is controlled throughout the pulling process.

[0031] The ingot puller apparatus **100** may include a heat shield **151**. The heat shield **151** may shroud the ingot **113** such that the ingot **113** passes through an opening **160** formed by the heat shield **151**. The heat shield **151** may be disposed within the crucible assembly **102** during crystal growth (e.g., as shown in the terminal portion of the crucible assembly **102** as shown in FIG. **5**). The heat shield **151** is fixed and does not move within the ingot puller apparatus **100**.

[0032] Referring now to FIG. **2**, the ingot puller apparatus **100** includes an elliptical reflector **125** that is disposed above the crucible assembly **102** for melting the silicon charge **117**. The elliptical reflector **125** defines a reflector chamber **133** within reflector **125**. The elliptical reflector **125** is connected to the pull mechanism **114** such as by connecting the reflector **125** to the chuck **120**. The elliptical reflector **125** (i.e., a reflector includes a reflective surface with a cross-section defined by two focal points such that the sum of the distances to the two points is the same) may be half an ellipse or may be longer or shorter than half an ellipse (<0.5 length or >0.5 length). In some embodiments (e.g., passive reflector), the length may be <0.5 the length of the full ellipse). In embodiments having active heating, the length may be <0.5 length or >0.5 length the full ellipse length. The elliptical reflector **125** may have a diameter less than the diameter of the opening of the fixed heat shield **151** (e.g., between 50% and 100% or between 75% and 100% of the diameter of the opening **160**).

[0033] The elliptical reflector **125** may be made of graphite and may be coated with molybdenum, tantalum or hafnium. In some embodiments, the elliptical reflector **125** is an assembly such as a welded quartz assembly having an interior volume with reflective interior coating such as platinum or other coating suitable for high infrared reflection.

[0034] In the illustrated embodiment, an upper heater **130** is disposed within the reflector chamber **133**. The upper heater **130** is supported by the pull mechanism **114** and may be suspended from the elliptical heat shield **125**. The upper heater **130** may be an electrical resistance heater. The upper heater **130** may have any suitable shape (coil, disk, annular, etc.). The upper heater **130** may be made of graphite and may be coated with SiC or hafnia. In other embodiments, the upper heater **130** may be made of tungsten encased with quartz or sapphire glass.

[0035] Before ingot growth, the crucible assembly **102** is filled with solid silicon to form the silicon charge **117** (FIG. **1**). After the solid silicon charge **117** is added to the crucible assembly **102**, the elliptical reflector **125** is connected to the pull mechanism **114** such as by connection to the chuck **120**. The pull mechanism **114** is operated to lower the elliptical reflector **125** toward the charge **117** of solid silicon. The upper heater **130** is powered to direct radiant heat **140** downward toward the charge **117** and upward toward the elliptical reflector **125**. Radiant heat **140** that is directed toward the elliptical reflector **125** is reflected through an opening **162** down into the charge **117**. In addition to powering the upper heater **130**, the bottom heater **126** is powered to melt the charge **117** and form the silicon melt **104** (FIG. **3**). Optionally, the side heater **135** may be powered with the upper heater **130** and bottom heater **126** to form the silicon melt **104**.

[0036] As shown in FIGS. **2** and **6**, the elliptical reflector **125** is shaped to focus energy to the upper portion of the silicon charge **117**. The reflected radiant heat may converge at or near a focal point P.sub.125 within the charge **117** (i.e., the focal points and length of the ellipse chosen such that the reflected radiant heat converges at a point P.sub.125). The focal point P.sub.125 may be within the upper portion of the silicon charge **117** (i.e., upper 50% or upper 25%).

[0037] Once the silicon charge **117** melts to form the silicon melt **104** (or toward the end of meltdown), the elliptical reflector **125** and upper heater **130** are removed from the ingot puller apparatus **100** (e.g., by operating the pull mechanism **114** to lift the reflector **125** and upper heater **130**). The elliptical reflector **125** and upper heater **130** may be pulled up into a receiving chamber (not shown) of the ingot puller apparatus **100** and may then be isolated from the lower portion of the ingot puller apparatus. Once the reflector **125** and heater **130** are disconnected from the chuck **120**, a seed crystal **122** (FIG. **3**) may be connected to the chuck **120**. The pull mechanism **114** may be operated to lower the chuck **120** and seed crystal **122** (after the isolation chamber is brought up to temperature) and the seed crystal **122** may be contacted with the melt **104** (FIG. **3**) to commence pulling the single crystal silicon ingot **113** (FIG. **4**) from the melt **104**).

[0038] As noted above, in the illustrated embodiment, the upper heater **130** is within the reflector chamber **133**. In other embodiments, the upper heater **130** is not disposed within the reflector chamber **133** (i.e., is disposed below the reflector **125**). In yet other embodiments, the ingot puller apparatus **100** does not include an upper heater (e.g., the reflector **125** is passive and side and/or bottom heaters **126**, **135** are operated with stray heat being reflected back toward the charge **117**). In the illustrated embodiments, a single elliptical reflector is shown. In other embodiments, the ingot puller apparatus **100** includes more than one elliptical reflector (e.g., two, three, four or more elliptical reflectors). In some embodiments, the elliptical reflector **125** is water cooled.

[0039] The ingot growth process may be a batch process in which polycrystalline silicon is not added to the crucible assembly **102** during ingot growth. In other embodiments, a continuous Czochralski process is used in which polycrystalline silicon is added to the crucible assembly **102** during ingot growth (e.g., with the crucible assembly having one or more fluid barriers that divide the crucible assembly into various zones). In embodiments in which continuous Czochralski is used, the solid silicon may be added to a drop zone in the crucible assembly **102** (e.g., an outer melt zone of the crucible assembly **102** that is below a polysilicon feed tube through which solid silicon is added to the melt **104**). The elliptical reflector **125** may be arranged in the ingot puller apparatus such that radiant heat (e.g., from upper heater **130** or from a side heater **135**) is directed to the drop zone.

[0040] Another embodiment of an ingot puller apparatus **200** is shown in FIG. **7**. The components shown in FIG. **7** that are analogous to those of FIGS. **1-6** are designated by the corresponding reference number of FIGS. **1-6** plus “**100**” (e.g., part **126** becomes **226**). The ingot puller apparatus **200** may be identical to the ingot puller apparatus **200** of FIGS. **1-6** with the exception that the ingot puller apparatus includes a torus-shaped elliptical reflector **225**. In the illustrated embodiment, the apparatus **100** includes an annular upper heater **230**. The torus-shaped elliptical reflector **225** includes a central opening **247**. The central opening **247** enables a polysilicon feed tube **250** (which may be made of silicon) to be lowered through the reflector **225** to allow solid polysilicon to be added to the crucible **202**. The reflector **230** may be connected to and lowered with the tube **250**. The polysilicon feed tube **250** may be lowered and raised by the pull mechanism **114**.

[0041] Compared to conventional methods for melting a silicon charge, the methods of the present disclosure have several advantages. By heating the silicon charge bi-directionally from below and above the melt, the duration of meltdown may be shortened which increases throughput of the ingot

production process. By reflecting heat back toward the charge, efficiency of the meltdown process is improved. Heating the charge from above allows the shape of the charge during meltdown to be changed and prevents or reduces the collapse of the charge into a melt pool that forms below the charge. In embodiments in which the elliptical reflector converges radiant heat to a focal point, heating at the focal point may be more concentrated which promotes meltdown of the silicon. A torus-shaped reflector allows the silicon feed tube to be relatively cooler which protects the relatively fragile feed tube.
[0042] As used herein, the terms “about,” “substantially,” “essentially” and “approximately” when used in conjunction with ranges of dimensions, concentrations, temperatures or other physical or chemical properties or characteristics is meant to cover variations that may exist in the upper and/or lower limits of the ranges of the properties or characteristics, including, for example, variations resulting from rounding, measurement methodology or other statistical variation.
[0043] When introducing elements of the present disclosure or the embodiment(s) thereof, the articles “a,” “an,” “the,” and “said” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” “containing,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. The use of terms indicating a particular orientation (e.g., “top,” “bottom,” “side,” etc.) is for convenience of description and does not require any particular orientation of the item described.
[0044] As various changes could be made in the above constructions and methods without departing from the scope of the disclosure, it is intended that all matter contained in the above description and shown in the accompanying drawing[s] shall be interpreted as illustrative and not in a limiting sense.

Claims

1. An ingot puller apparatus for manufacturing a single crystal silicon ingot, the ingot puller apparatus comprising: a crucible assembly for holding a silicon melt; a crystal puller housing that defines a growth chamber for pulling a silicon ingot from the silicon melt, the crucible assembly being disposed within the growth chamber; a side heater disposed radially outward to the crucible assembly; an elliptical reflector disposed above the crucible assembly, the elliptical reflector defining a reflector chamber; and an upper heater disposed within the reflector chamber.
2. The ingot puller apparatus as set forth in claim 1 wherein the upper heater is an electrical resistance heater.
3. The ingot puller apparatus as set forth in claim 1 wherein the elliptical reflector is the only elliptical reflector disposed above the crucible assembly.
4. The ingot puller apparatus as set forth in claim 1 wherein the upper heater comprises graphite coated with silicon carbide or hafnia.
5. The ingot puller apparatus as set forth in claim 1 wherein the elliptical reflector comprises graphite coated with molybdenum, tantalum or hafnium.
6. The ingot puller apparatus as set forth in claim 1 comprising a bottom heater disposed below the crucible assembly.
7. An ingot puller apparatus for manufacturing a single crystal silicon ingot, the ingot puller apparatus comprising: a crucible assembly for holding a silicon melt; a crystal puller housing that defines a growth chamber for pulling a silicon ingot from the silicon melt, the crucible assembly being disposed within the growth chamber; a single elliptical reflector disposed above the crucible assembly, the single elliptical reflector defining a reflector chamber; and an upper heater disposed within the reflector chamber.
8. The ingot puller apparatus as set forth in claim 7 wherein the upper heater is an electrical resistance heater.
9. The ingot puller apparatus as set forth in claim 7 wherein the upper heater comprises graphite

coated with silicon carbide or hafnia.

10. The ingot puller apparatus as set forth in claim 7 wherein the elliptical reflector comprises graphite coated with molybdenum, tantalum or hafnium.

11. A method for preparing a single crystal silicon ingot in an ingot puller apparatus, the ingot puller apparatus comprising a crucible assembly for holding a melt of silicon, a growth chamber for pulling a silicon ingot from the melt along a pull axis, a side heater disposed radially outward to the crucible assembly, and a pull mechanism for raising and lowering the crucible assembly during crystal growth relative to the pull axis, the method comprising: adding a charge of solid silicon to the crucible assembly; connecting an elliptical reflector to the pull mechanism; operating the pull mechanism to lower the elliptical reflector toward the charge of solid silicon; powering an upper heater to direct radiant heat toward the elliptical reflector, the elliptical reflector reflecting radiant heat into the charge of solid silicon to melt the silicon charge and form a silicon melt; removing the elliptical reflector from the ingot puller apparatus; connecting a seed crystal to the pull mechanism; operating the pull mechanism to lower the seed crystal to contact the silicon melt; and operating the pull mechanism to raise the seed crystal to cause a silicon ingot to be withdrawn from the melt.

12. The method as set forth in claim 11 further comprising powering a bottom heater disposed the crucible assembly while powering the upper heater to melt the silicon charge and form a silicon melt.

13. The method as set forth in claim 12 further comprising powering a side heater disposed radially outward to the crucible assembly while powering the upper heater and bottom heater to melt the silicon charge and form a silicon melt.

14. The method as set forth in claim 11 wherein the elliptical reflector is the only elliptical reflector used to melt the silicon charge and form a silicon melt.

15. The method as set forth in claim 11 wherein the elliptical reflector defines a reflector chamber, the upper heater being disposed within the reflector chamber.

16. The method as set forth in claim 11 wherein the upper heater is a side heater disposed radially outward to the crucible assembly.

17. The method as set forth in claim 11 wherein solid silicon is not added to the melt while withdrawing the single crystal silicon ingot.

18. The method as set forth in claim 11 wherein solid silicon is added to the melt while withdrawing the single crystal silicon ingot, wherein solid silicon is added to a drop zone in the crucible assembly, the elliptical reflector directing radiant heat to the drop zone.

19. An ingot puller apparatus for manufacturing a single crystal silicon ingot, the ingot puller apparatus comprising: a crucible assembly for holding a silicon melt; a crystal puller housing that defines a growth chamber for pulling a silicon ingot from the silicon melt, the crucible assembly being disposed within the growth chamber; a side heater disposed radially outward to the crucible assembly; an elliptical reflector disposed above the crucible assembly, the elliptical reflector defining a reflector chamber, the elliptical reflector being torus-shaped and having a central opening.

20. The ingot puller apparatus as set forth in claim 19 wherein the elliptical reflector is connected to a polysilicon feed tube for adding a charge of polysilicon to the crucible assembly.