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 reflector assembly has an opening for receiving the single crystal silicon ingot as the ingot is pulled through the reflector assembly. The reflector assembly includes an upper flange and a shield that extends downward from the upper flange. The ingot puller apparatus includes first and second support shafts for supporting the reflector assembly. The first and second support shafts extend upward from the reflector assembly. Each support shaft is connected to the upper flange by a flexible joint.

[0010] 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.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a cross-section of an ingot puller apparatus during ingot growth;

[0012] FIG. 2 is a schematic of an ingot puller apparatus having an upper segment and lower segment that is removably connected to the upper segment;

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 (not shown) 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 crystal growth process may be a batch process in which solid silicon is initially added to the crucible assembly 102 to form a silicon melt without additional solid-silicon being added to the crucible assembly 102 during crystal growth. In other embodiments, the crystal growth process is a continuous Czochralski process in which an amount of silicon is added to the crucible assembly during ingot growth.

[0031] 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 sidewall 131 as the crucible assembly 102 travels up and down the pull axis A. 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 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.

[0032] The ingot puller apparatus 100 may include a reflector assembly 151. The reflector assembly 151 includes an opening 157 through which the single crystal silicon ingot 113 is pulled during ingot growth. 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.

[0033] The illustrated ingot puller apparatus 100 is an example and any ingot puller apparatus 100 that includes a reflector assembly 151 may be used unless stated otherwise.

[0034] An embodiment of a reflector assembly 251 is shown in FIGS. 3-8. The reflector assembly 251 includes an upper flange 260 (or simply “flange”) and a shield 264 that extends downward from the upper flange 260. The reflector assembly 251 includes an opening 257 through which the single crystal silicon ingot is pulled. The reflector assembly 251 may include various components which together form the flange and/or shield including various plates and bands (e.g., the flange may be made of various support plates that support the various insulated components). The shield 264 may comprise insulation and an outer cap that reduces or eliminates particles from dislodging from the shield 264 into the melt.

[0035] The ingot puller apparatus 100 includes two or more support shafts 266, 269 (e.g., first and second support shafts 266, 269) that extend upward from the reflector assembly 251 and support the reflector assembly 251. While the illustrated embodiment includes two support shafts 266, 269, more than two support shafts may be used

heating (and contraction during cooling). Any suitable joint that allows for radial movement of the reflector assembly 251 may be used. In the illustrated embodiment, each joint 301, 303 comprises two ball and socket joints. In other embodiments, a single ball and socket joint could be used. In other embodiments, the joint (e.g., top or bottom) comprises a wire or cable. In yet other embodiments the joint includes cylinders or cam bodies (e.g., as a substitute for the ball). The joint may include two connections with the top connection being a flexible joint and the bottom connection including a pin through a shaft, a clamp, or a collet.

[0039] The two joints 301, 303 may be identical and an exemplary joint 301, 303 is shown in FIG. 6. Each joint 301, 303 includes a stud 310 and first and second ball members 313, 316 that extend from each end of the stud 310. The first ball member 313 is disposed within a first socket 320. A first socket housing 325 defines the first socket 320. The first socket housing 325 is secured to a linkage 329 (FIG. 4) that is connected to the joist 275, 277 by pins 327. The second ball member 316 is disposed within a second socket 323. A second socket housing 331 defines the second socket 323.

[0040] As shown in FIG. 7, the second socket housing 331 of each joint 301, 303 extends through the flange 260 of the reflector assembly 251. A rod 365 (FIG. 6) extends from the second socket housing 331. Each rod 365 is received within a support band 368 disposed below the flange 260. The support band 368 rests on a ledge 366 (FIG. 6) of each rod 365. The support band 368 may be disposed within a groove (not shown) formed in the bottom surface of

CLAIMS:

1. An ingot puller apparatus for producing 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 reflector assembly having an opening for receiving the single crystal silicon ingot as the ingot is pulled through the reflector assembly, the reflector assembly comprising:

an upper flange; and

a shield that extends downward from the upper flange;

two or more support shafts for supporting the reflector assembly, the support shafts extending upward from the reflector assembly; and

two or more joists, each joist being connected to a support shaft toward a lower end of the support shaft, each joist being connected to the flange by first and second joints that are separated from each other along a longitudinal axis of the joist.

2. The ingot puller apparatus as set forth in claim 1 wherein only two support shafts support the reflector assembly.

3. The ingot puller apparatus as set forth in claim 1 or claim 2 wherein, during ingot growth, the

reflector assembly is not supported in the ingot puller apparatus by any structure other than support shafts.

4. The ingot puller apparatus as set forth in any one of claims 1 to 3 wherein the first and second joint is each a flexible joint.

5. The ingot puller apparatus as set forth in claim 4 wherein each flexible joint is a ball and socket joint.

6. The ingot puller apparatus as set forth in claim 5 wherein each flexible joint comprises two ball and socket joints.

7. The ingot puller apparatus as set forth in any one of claims 1 to 6 wherein the two or more support shafts are water cooled, each support shaft comprising an inlet for adding water to the support shaft and an outer for removing water from the support shaft.

8. The ingot puller apparatus as set forth in any one of claims 1 to 7 comprising an outer gas shield, the outer gas shield abutting an outer circumferential edge of the flange.

9. The ingot puller apparatus as set forth in any one of claims 1 to 8 wherein each support shaft extends through the crystal puller housing at a support shaft port.

10. The ingot puller apparatus as set forth in any one of claims 1 to 9 comprising a support band disposed below the flange for supporting the reflector assembly.

11. The ingot puller apparatus as set forth in any one of claims 1 to 10 wherein the shield includes

insulation and an outer cap, the insulation being disposed within the outer cap.

12. An ingot puller apparatus for producing 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 reflector assembly having an opening for receiving the single crystal silicon ingot as the ingot is pulled through the reflector assembly, the reflector assembly comprising:

an upper flange; and

a shield that extends downward from the upper flange; and

first and second support shafts for supporting the reflector assembly, the first and second support shafts extending upward from the reflector assembly, the ingot puller apparatus not comprising more than two support shafts, each support shaft being connected to the crystal puller housing at a support shaft port.

13. The ingot puller apparatus as set forth in claim 12 wherein, during ingot growth, the reflector assembly is not supported in the ingot puller apparatus by any structure other than support shafts.

14. The ingot puller apparatus as set forth in claim 12 or claim 13 wherein the support shaft is connected to the upper flange by at least one flexible joint.

15. The ingot puller apparatus as set forth in claim 14 wherein the flexible joint is a ball and socket joint.

16. The ingot puller apparatus as set forth in any one of claims 12 to 15 comprising an outer gas shield and wherein the upper flange comprises a support plate, the outer gas shield abutting an outer circumferential edge of the support plate.

17. The ingot puller apparatus as set forth in any one of claims 12 to 16 wherein the shield includes insulation and an outer cap, the insulation being disposed within the outer cap.

18. The ingot puller apparatus as set forth in any one of claims 12 to 17 wherein the first and second support shafts are water cooled, each support shaft comprising an inlet for adding water to the support shaft and an outer for removing water from the support shaft.

19. The ingot puller apparatus as set forth in any one of claims 12 to 18 comprising a support band disposed below the flange for supporting the reflector assembly.

20. An ingot puller apparatus for producing 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 reflector assembly having an opening for receiving the single crystal silicon ingot as the ingot is pulled through the reflector assembly, the reflector assembly comprising:

an upper flange;

a shield that extends downward from the upper flange; and

first and second support shafts for supporting the reflector assembly, the first and second support shafts extending upward from the reflector assembly, each support shaft being connected to the upper flange by a flexible joint.

21. The ingot puller apparatus as set forth in claim 20 wherein the flexible joint is a ball and socket joint.

22. The ingot puller apparatus as set forth in claim 20 or claim 21 wherein, during ingot growth, the reflector assembly is not supported in the ingot puller apparatus by any structure other than support shafts.

23. The ingot puller apparatus as set forth in any one of claims 20 to 22 comprising an outer gas shield and wherein the upper flange comprises a support plate, the outer gas shield abutting an outer circumferential edge of the support plate.

24. The ingot puller apparatus as set forth in any one of claims 20 to 23 wherein the shield includes insulation and an outer cap, the insulation being disposed within the outer cap.

25. The ingot puller apparatus as set forth in any one of claims 20 to 24 wherein the first and second support shafts are water cooled, each support shaft comprising an inlet for adding water to the support shaft and an outer for removing water from the support shaft.

26. The ingot puller apparatus as set forth in any one of claims 20 to 25 comprising a support band disposed below the flange for supporting the reflector assembly.