silicon melt 104 along a pull axis $A_{100}$. Referring now to FIG. 2, the growth chamber 152 includes two portions - a lower segment chamber 155 (or simply "lower chamber") and an upper growth chamber 165 (or simply "upper chamber") disposed above the lower segment chamber 155 that are separated by an isolation valve 170 (or isolation valve housing 172). The hotzone of the ingot puller apparatus 100 (e.g., crucible, reflector, susceptor, heaters, and the like) is disposed within the lower chamber 155. During ingot growth, the ingot 113 is pulled through the lower chamber 155 and continues to be pulled through the upper chamber 165 as the ingot is lengthened.

[0026] The ingot puller housing 108 includes a lower segment 119 that defines the lower chamber 155 and an upper segment 140 that defines the upper chamber 165. At least a portion of the lower segment 119 has a diameter greater than the upper segment 140. The lower segment 119 includes a dome-shaped portion 169 which tapers in size to the diameter of the upper segment 140. The upper segment 140 is generally cylindrical in shape and includes an upper end 163 and lower end 159.

[0027] The crucible assembly 102 (FIG. 1) is disposed in the lower chamber 155. The crucible assembly 102 has a sidewall 131 and floor 129 and rests on a susceptor 106. The susceptor 106 is supported by a shaft 105. The susceptor 106, crucible assembly 102, shaft 105, and ingot 113 have a common longitudinal axis or "pull axis" $A_{100}$.

[0028] The ingot puller apparatus 100 includes a pulling mechanism 114 for growing and pulling an ingot 113 from the melt 104. The pulling mechanism 114 includes a

the inlet 176 of the process gas feed assembly 174 and with the plurality of outlets 205 of the shower plate 200.

[0047] Each outlet 205 of the shower plate has a longitudinal axis A205. In the embodiment illustrated in FIG. 6, the longitudinal axis A205 is parallel to the pull axis A100 of the ingot puller apparatus. In other embodiments, the longitudinal axis A205 of each outlet 205 forms an angle with the pull axis. The angle may be 45° or less, 30° or less, 25° or less or 10° or less.

[0048] In some embodiments and as shown in FIG. 6, the shower plate 200 is connected (e.g., cast with, welded, or fastened) to the isolation valve 170. The shower plate 200 moves with the isolation valve 170 between the open position and the closed position.

[0049] In some embodiments, the flow of process gas is controlled during ingot growth (i.e., during ingot cooling) to reduce deposit formation in the lower chamber 155. After ingot growth (i.e., formation of an end cone), the single crystal silicon ingot 113 (FIG. 1) is separated from the melt 104. The ingot 113 (e.g., the entire ingot) is pulled into the upper chamber 165 and above the isolation valve 170 by the pulling mechanism 114. The pulling mechanism 114 is stopped and the single crystal silicon ingot cools. During cooling, the isolation valve 170 is in the open position and process gas flows through the second inlet 199 (Fig. 2), through the upper chamber 165, through the isolation valve housing 172 and into the lower chamber 155 (without flow through the first inlet 176). The cooled ingot 113 may be withdrawn from the upper segment 140 (through a cover that is opened for removal of

EXAMPLES

[0053] The processes of the present disclosure are further illustrated by the following Examples. These Examples should not be viewed in a limiting sense.

**Example 1: Effect of an Open Isolation Valve during Ingot Cooling on Loss of Zero Dislocation**

[0054] In an ingot puller apparatus similar to the example apparatus shown in FIGS. 1-2, after ingot formation, the single crystal silicon ingot was pulled fully into the upper segment chamber 165. The isolation valve 170 was left open during cooling of the ingot in the upper segment chamber. The second valve 211 was left open and the first valve 209 was closed such that process gas flowed vertically through the upper chamber 165 and into the lower chamber 155. By positioning the valve 170 to be open during cooling, the valve 170 was open an additional 1-4 hours compared to the process of record. This was repeated for a number of ingots (multiple pullers over a series of months) to determine the effect on Zero Dislocation (ZD) success. As shown in FIG. 9, reducing the time that the isolation valve was closed ("After") increased ZD success. Opening the isolation valve during cooling reduced oxide and volatile gas deposition on the upper portions of the lower segment chamber 155 and cooling jacket which resulted in a cleaner ingot puller apparatus and reduced particles falling into the melt and causing loss of zero dislocation.

[0055] 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

CLAIMS:

1. An ingot puller apparatus for producing a single crystal silicon ingot comprising:

a crucible assembly for holding a silicon melt;

an ingot puller housing that defines a growth chamber for pulling a single crystal silicon ingot from the silicon melt, the crucible assembly being disposed within the growth chamber, the ingot puller housing comprising:

a lower segment that defines a lower segment chamber, the crucible assembly being disposed in the lower segment chamber; and

an upper segment disposed above the lower segment that defines an upper segment chamber; and

an isolation valve that is moveable between an open position in which the lower segment chamber is in fluid communication with the upper segment chamber and a closed position in which the lower segment chamber is sealed from the upper segment chamber;

a process gas feed assembly comprising:

an inlet that extends through the ingot puller housing for introducing a process gas into the growth chamber; and

a nozzle in fluid communication with the inlet for directing process gas into the lower segment chamber.

2. The ingot puller apparatus as set forth in claim 1 wherein the nozzle has a discharge axis, the discharge axis forming an angle with a pull axis of the ingot puller apparatus, the angle being 45° or less.

3. The ingot puller apparatus as set forth in claim 2 wherein the nozzle has a discharge axis, the discharge axis being parallel to pull axis of the ingot puller apparatus.

4. The ingot puller apparatus as set forth in any one of claims 1 to 3 further comprising an annular process gas manifold, the manifold being disposed below the isolation valve relative to a pull axis of the ingot puller apparatus, the manifold comprising a process gas plenum therein, the process gas plenum being in fluid communication with nozzle.

5. The ingot puller apparatus as set forth in claim 4 wherein the annular process gas manifold comprises one or more outlets that extend through an inner surface of the manifold and that are in fluid communication with the process gas plenum, the nozzle being aligned with an outlet of the process gas manifold.

6. The ingot puller apparatus a set forth in any one of claims 1 to 4 comprising at least two, at least four, or at least 10 nozzles in fluid communication with the inlet for directing process gas into the lower segment chamber.

7. The ingot puller apparatus as set forth in any one of claims 1 to 6 wherein the nozzle comprises a nozzle inlet and a nozzle outlet, the nozzle inlet having a cross-sectional area greater than a cross-sectional area of the nozzle outlet.

8. The ingot puller apparatus as set forth in any one of claims 1 to 7 wherein the inlet is a first inlet, the ingot puller apparatus comprising a second inlet

that extends through the ingot puller housing for introducing a process gas into the upper segment chamber.

9. The ingot puller apparatus as set forth in any one of claims 1 to 8 wherein the lower segment includes a dome-shaped section and the upper segment is cylindrical, the upper segment having a diameter less than a diameter of the lower segment.

10. An ingot puller apparatus for producing a single crystal silicon ingot comprising:

a crucible assembly for holding a silicon melt;

an ingot puller housing that defines a growth chamber for pulling a single crystal silicon ingot from the silicon melt along a pull axis, the crucible assembly being disposed within the growth chamber, the ingot puller housing comprising:

a lower segment that defines a lower segment chamber, the crucible assembly being disposed in the lower segment chamber; and

an upper segment disposed above the lower segment that defines an upper segment chamber; and

an isolation valve that is moveable between an open position in which the lower segment chamber is in fluid communication with the upper segment chamber and a closed position in which the lower segment chamber is sealed from the upper segment chamber;

a process gas feed assembly comprising:

an inlet that extends through the ingot puller housing for introducing a process gas into the growth chamber; and

a shower plate disposed below the isolation valve, the shower plate being in fluid communication with the inlet, the shower plate comprising a plurality of outlets for discharging process gas into the lower segment chamber.

11. The ingot puller apparatus as set forth in claim 10 wherein each outlet has a longitudinal axis, the longitudinal axis (1) being parallel to the pull axis or (2) forming an angle with the pull axis of 45° or less.

12. The ingot puller apparatus as set forth in claim 11 wherein the longitudinal axis is parallel to the pull axis.

13. The ingot puller apparatus as set forth in claim 11 wherein the longitudinal axis of each outlet forms an angle with the pull axis of 10° or less.

14. The ingot puller apparatus as set forth in any one of claims 10 to 13 wherein the shower plate is connected to the isolation valve and moves with the isolation valve between the open position and the closed position.

15. The ingot puller apparatus as set forth in any one of claims 10 to 14 wherein the isolation valve defines a process gas plenum therein, the process gas plenum being in fluid communication with the inlet of the process gas feed assembly and with the plurality of outlets of the shower plate.

16. The ingot puller apparatus as set forth in any one of claims 10 to 15 wherein the shower plate comprises at least 5 openings.

17. The ingot puller apparatus as set forth in any one of claims 10 to 16 wherein the inlet is a first inlet, the ingot puller apparatus comprising a second inlet that extends through the ingot puller housing for introducing a process gas into the upper segment chamber.

18. The ingot puller apparatus as set forth in any one of claims 10 to 17 wherein the lower segment includes a dome-shaped section and the upper segment is cylindrical, the upper segment having a diameter less than a diameter of the lower segment.

19. A method for forming a single crystal silicon ingot in an ingot puller apparatus, the ingot puller apparatus comprising a crucible assembly for holding a silicon melt, an ingot puller housing that defines a growth chamber for pulling a single crystal silicon ingot from the silicon melt, the crucible assembly being disposed within the growth chamber, the ingot puller housing comprising a lower segment that defines a lower segment chamber, the crucible assembly being disposed in the lower segment chamber, and an upper segment disposed above the lower segment that defines an upper segment chamber, and an isolation valve that is moveable between an open position in which the lower segment chamber is in fluid communication with the upper segment chamber and a closed position in which the lower segment chamber is sealed from the upper segment chamber, the method comprising:

adding a charge of solid-state silicon to the crucible assembly;

heating the crucible assembly comprising the charge of silicon to cause a silicon melt to form in the crucible assembly;

contacting a silicon seed crystal with the silicon melt;

withdrawing the silicon seed crystal along a pull axis to grow a single crystal silicon ingot;

separating the single crystal silicon ingot from the melt;

cooling the single crystal silicon ingot while the ingot is fully within the upper segment chamber after separating the single crystal silicon ingot from the melt, the isolation valve being in the open position while cooling the single crystal silicon ingot;

directing process gas through the upper segment chamber and into the lower segment chamber while cooling the single crystal silicon ingot in the upper segment chamber; and

withdrawing the single crystal silicon ingot from the upper segment chamber, the isolation valve being in the closed position while withdrawing the single crystal silicon ingot.

20. The method as set forth in claim 19 wherein the ingot puller apparatus comprises:

a first inlet for introducing process gas directly into the lower segment chamber;

a first process gas valve moveable between an open position in which the first inlet is in fluid communication with a source of process gas and a closed position in which process gas cannot flow from the source of process gas through the first inlet;

a second inlet for introducing process gas directly into the upper segment chamber; and

a second process gas valve moveable between an open position in which the second inlet is in fluid communication with the source of process gas and a closed position in which process gas cannot flow from the source of process gas through the second inlet, wherein the first process gas valve is in the closed position and the second process gas valve is in the open position while cooling the single crystal silicon ingot in the upper segment chamber.

21. The method as set forth in claim 20 wherein the first process gas valve is in the open position and the second process gas valve is in the closed position while withdrawing the single crystal silicon ingot from the upper segment chamber.