includes a notch 164 (Fig. 5) that enables access to the receptacle 156. In the loading position (Fig. 2), the receptacle 156 may be removed from the elongate member 150 to charge it with dopant. The notch 164 is aligned with an access port 166 when the receptacle 156 is in the loading position to allow access to the receptacle 156. The receptacle 156 may be grasped by a connecting loop 172 of the receptacle 156 to pull the receptacle 156 through the notch 164 and access port 166. In other configurations, dopant may be added to the receptacle 156 when the receptacle 156 is disposed in the elongate member 150.

[0043] In the feed position of the receptacle (FIGS. 3 and 4), a dopant gas is produced from the solid-phase dopant. The dopant gas travels down an exit tube 168 and through an outlet 170 where it is directed to the surface of the melt 108.

[0044] In the illustrated embodiment, the receptacle 156 is a capsule 158 (Fig. 9) that holds the solid-phase dopant. The capsule 158 includes an outer capsule housing 180. A weir 182 is disposed within the outer capsule housing 180. The weir 182 forms a channel 184 therein. The weir 182 has an upper end 188 and a lower end 190 that are each open such that gas may pass through the channel 184. An annular chamber 194 is disposed between the weir 182 and the outer capsule housing 180. Solid dopant 174 (e.g., boric acid) is disposed within the annular chamber 194 and rests on the capsule floor 198. When the receptacle 156 is in its lowered position (Figs. 3 and 4), the solid-phase dopant 174 heats which causes the dopant to either sublime or to melt and evaporate. The dopant gas rises in the annular chamber 194 and enters the weir channel 184 through the upper end 188 of the weir 182.

[0053] The ingot puller apparatus 400 includes a dopant vaporization unit 414 that feeds doped gas to a dopant conduit 430. The doped gas passes through the dopant conduit 430 to contact the melt 408 to cause the melt 408 to be doped. The dopant conduit 430 includes a gas inlet 422 (Fig. 11) disposed exterior to the ingot puller chamber 402 and a gas outlet 426 disposed in the ingot puller inner chamber 402 and positioned relatively near the surface of the melt 408.

[0054] The dopant vaporization unit 414 is disposed exterior to the ingot puller inner chamber 402. The dopant vaporization unit 414 includes a dopant chamber 424 (Fig. 13) for holding the solid-phase dopant (e.g., boric acid as discussed in the method above). A process gas (e.g., argon) may be circulated through the vaporization unit 414 through first and second process gas inlets 436, 440. A doped gas outlet 452 of the vaporization unit 414 is in fluid communication with the dopant conduit 430 (Fig. 11) to move doped gas to the surface of the melt 408.

[0055] Surrounding the dopant chamber 424 is a heating chamber 472 (Fig. 13). A heating device 428 (e.g., resistive heating element) heats gases circulating in the vaporization unit 414. The heated gases contact the solid-phase dopant in the dopant chamber 242 causing a dopant gas to be produced (e.g., through sublimation or by liquefaction and vaporization of the solid-phase dopant). The dopant gas is picked up by the process gas to produce a doped process gas that is discharged through the doped gas outlet 452 and into the dopant conduit 430 (Fig. 11). The vaporization unit 414 includes a thermal shield 476 to reduce heat lost through the walls of the heating chamber

CLAIMS:

1. A method for producing a single crystal silicon ingot from a silicon melt held within a crucible, the method comprising:

adding polycrystalline silicon to the crucible, the crucible being disposed within an ingot puller inner chamber;

heating the polycrystalline silicon to cause a silicon melt to form in the crucible;

pulling a single crystal silicon ingot from the silicon melt;

providing a source of solid-phase boric acid;

producing a boron-containing gas from the solid-phase boric acid; and

contacting the boron-containing gas with a surface of the melt to cause boron to enter the melt as a dopant while pulling the single crystal silicon ingot from the melt.

2. The method as set forth in claim 1 comprising adding an n-type dopant to the crucible prior to pulling the single crystal silicon ingot from the melt.

3. The method as set forth in claim 2 wherein the n-type dopant is phosphorous.

4. The method as set forth in any one of claims 1 to 3 wherein the boron-containing gas is produced by:

liquefying the solid-phase boric acid to produce a boric acid liquid; and

evaporating the boric acid liquid to produce the boron-containing gas.

5. The method as set forth in any one of claims 1 to 4 wherein the solid-phase boric acid is disposed within the ingot puller inner chamber.

6. The method as set forth in claim 5 wherein the solid-phase boric acid is disposed within a capsule.

7. The method as set forth in any one of claims 1 to 4 wherein the solid-phase boric acid is disposed exterior to an ingot puller housing in which the crucible is disposed.

8. The method as set forth in claim 7 wherein the solid-phase boric acid is within a chamber of a vaporization unit.

9. An ingot puller apparatus for producing a doped single crystal silicon ingot, the ingot puller apparatus comprising:

an ingot puller outer housing;

an ingot puller inner chamber formed within the ingot puller outer housing;

a crucible disposed within the ingot puller inner chamber;

an outer feed tube that is at least partially disposed exterior to the ingot puller outer housing, the outer feed tube defining an outer feed tube chamber and having a distal end, proximal end and an outer feed tube axis that extends through the distal end and the proximal end;

an elongate member that is moveable within the outer feed tube chamber along the outer feed tube axis; and

a dopant receptacle coupled to the elongate member that is moveable between a loading position in which the dopant receptacle is disposed exterior to the ingot puller outer housing and a feed position in which the dopant receptacle is disposed within the ingot puller inner chamber.

10. The ingot puller apparatus as set forth in claim 9 wherein the dopant receptacle is a capsule that is separable from the elongate member.

11. The ingot puller apparatus as set forth in claim 10 wherein the capsule comprises:

an outer capsule housing; and

a weir disposed within the outer capsule housing, the weir forming a channel for dopant gas to pass through, the weir having an upper end and a lower end, the upper end and lower ends being open, an annular chamber disposed between the weir and the ingot puller outer housing for holding solid-phase dopant.

12. The ingot puller apparatus as set forth in any one of claims 9 to 11 comprising a tube disposed below the dopant receptacle to direct dopant gas to a surface of a melt.

13. The ingot puller apparatus as set forth in any one of claims 9 to 12 wherein the elongate member is a tube.

14. The ingot puller apparatus as set forth in any one of claims 9 to 13 further comprising a valve for sealing the ingot puller inner chamber when the elongate member is withdrawn from the ingot puller inner chamber.

15. The ingot puller apparatus as set forth in any one of claims 9 to 14 comprising a translation device for moving the dopant receptacle between the loading position and the feed position.

16. The ingot puller apparatus as set forth in claim 15 wherein the translation device is a magnetically coupled through-wall translation unit.

17. The ingot puller apparatus as set forth in claim 15 wherein the translation device is a bellows system.

18. An ingot puller apparatus for producing a doped single crystal silicon ingot, the ingot puller apparatus comprising:

an ingot puller outer housing;

an ingot puller inner chamber formed within the ingot puller outer housing;

a crucible disposed within the ingot puller inner chamber;

a dopant conduit having a gas inlet disposed exterior to the ingot puller inner chamber and a gas outlet disposed in the ingot puller inner chamber; and

a dopant vaporization unit disposed exterior to the ingot puller inner chamber and comprising:

a dopant chamber for holding solid-phase dopant;

a heating device for heating the solid-phase dopant and producing a dopant gas; and

an outlet through which the dopant gas passes, the outlet being in fluid communication with the dopant conduit.

19. The ingot puller apparatus as set forth in claim 18 further comprising an inlet for introducing a process gas, the inlet being in fluid communication with the dopant chamber, the process gas passing through the dopant chamber and through the outlet.