embodiments, the control unit 143 may include a memory 173 and processor 144 that processes the signals received from various sensors of the system 100 including, but not limited to, photocell 139 and diameter transducer 141, as well as to control one or more devices of system 100 including, but not limited to: crucible drive unit 107, crystal drive unit 121, heater power supply 123, vacuum pump 131, gas flow controller 129 (e.g., an argon flow controller), magnetic poles power supply 149, 151, and any combination thereof. The memory 173 may store instructions that, when executed by the processor 144 cause the processor to perform one or more of the methods described herein. That is, the instructions configure the control unit 143 to perform one or more methods, processes, procedures, and the like described herein.

[0036] Control unit 143 may be a computer system. Computer systems, as described herein, refer to any known computing device and computer system. As described herein, all such computer systems include a processor and a memory. However, any processor in a computer system referred to herein may also refer to one or more processors wherein the processor may be in one computing device or a plurality of computing devices acting in parallel. Additionally, any memory in a computer device referred to herein may also refer to one or more memories wherein the memories may be in one computing device or a plurality of computing devices acting in parallel. Further, the computer system may located near the system 100 (e.g., in the same room, or in an adjacent room), or may be remotely located and coupled to the rest of the system via a network, such as an Ethernet, the Internet, or the like.

other components and processes described herein. Each component and process also can be used in combination with other assembly packages and processes.

[0040] In one embodiment, the computer system may be configured to receive measurements from one or more sensors including, but not limited to: temperature sensor 139, diameter transducer 141, and any combination thereof, as well as to control one or more devices of system 100 including, but not limited to: crucible drive unit 107, crystal drive unit 121, heater power supply 123, vacuum pump 131, gas flow controller 129 (e.g., an argon flow controller), magnetic poles power supply 149, 151, and any combination thereof as described herein and illustrated in Fig. 4 in one embodiment. The computer system performs all of the steps used to control one or more devices of system 100 as described herein.

[0041] In accordance with embodiments of the present disclosure, while generating a horizontal magnetic field within the vacuum chamber 101, a plurality of process parameters are simultaneously regulated to reduce the oxygen concentration in the silicon ingot 27. The plurality of process parameters include a wall temperature of the crucible, a transport of silicon monoxide (SiO) from the crucible to the single crystal, and an evaporation rate of SiO from the melt.

[0042] In this embodiment, three process parameters are regulated simultaneously to facilitate producing silicon crystal ingots with a low oxygen concentration. Specifically, a wall temperature of crucible 10, a flow (i.e., transport) of silicon monoxide (SiO) from

rate in a range from 0.1 RPM to 5.0 RPM, from 0.7 RPM to 5 RPM, or from 1.2 RPM to 5.0 RPM.

[0047] In accordance with embodiments of the present disclosure, one or more of the methods for simultaneously regulating a plurality of process parameters described above may result in silicon ingots having a relatively low concentration of oxygen incorporated therein. For example, the resulting silicon ingots may have an oxygen concentration of less than about 15 ppma, less than about 8 ppma, or even less than about 5 ppma.

EXAMPLES

[0048] 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 MGP Position on Oi Concentration

[0049] FIG. 6 compares the flow fields along the planes that lie perpendicular to the applied horizontal magnetic field when the maximum gauss plane was 80 mm below the melt surface ("MGP -80 mm") and the maximum gauss plane was 80 mm above the melt surface ("MGP +80 mm"). FIG. 8 compares the flow field along planes that lie parallel to the magnetic field.

[0050] There are some similarities in flow features between the two positions - recirculating flow cells are established only in the perpendicular planes and absent in the parallel planes. In addition, both positions of the MGP develop a buoyancy cell in the bulk of the melt and a Taylor-Proudman cell underneath the rotating crystal.

CLAIMS:

1. A method for producing a silicon ingot, the method comprising:

melting polycrystalline silicon in a crucible enclosed in a vacuum chamber to form a melt, the melt having a melt free surface;

generating a horizontal magnetic field within the vacuum chamber;

dipping a seed crystal into the melt;

withdrawing the seed crystal from the melt to form the silicon ingot; and

simultaneously regulating a plurality of process parameters to reduce the oxygen concentration in the silicon ingot, wherein the plurality of process parameters include a wall temperature of the crucible, a transport of silicon monoxide (SiO) from the crucible to the silicon ingot, and an evaporation rate of SiO from the melt, wherein simultaneously regulating a plurality of process parameters comprises:

maintaining the position of a maximum gauss plane of the horizontal magnetic field above the melt free surface;

generating the horizontal magnetic field at a magnetic flux density of from 0.15 Tesla to about 0.4 Tesla; and

rotating the crucible (1) opposite a direction at which the ingot is rotated or (2) in the same direction at which the ingot is rotated, wherein:

when the crucible is rotated opposite a direction at which the ingot is rotated, the crucible is rotated at a rate in a range from 0.1 RPM to 1.2 RPM; and

when the crucible is rotated in the same direction at which the ingot is rotated, the crucible is rotated at a rate in a range from 1.2 RPM to 5.0 RPM.

2. The method as set forth in claim 1 wherein the maximum gauss plane is maintained at a position at least 20 mm above the melt free surface.

3. The method as set forth in claim 1 wherein the maximum gauss plane is maintained at a position at least 40 mm above the melt free surface.

4. The method as set forth in claim 1 wherein the maximum gauss plane is maintained at a position at least 60 mm above the melt free surface.

5. The method as set forth in claim 1 wherein the maximum gauss plane is maintained at a position at least 150 mm above the melt free surface.

6. The method as set forth in any one of claims 1 to 5 wherein the silicon ingot has a diameter of 300 mm or more.

7. The method as set forth in any one of claims 1 to 5 wherein the silicon ingot has a diameter of 300 mm.