METHODS FOR FORMING A SINGLE CRYSTAL SILICON INGOT WITH REDUCED CRUCIBLE EROSION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 63/112,431, filed November 11, 2020, which is incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The field of the disclosure relates to methods for forming a single crystal silicon ingot with reduced crucible erosion and, in particular, methods that involve addition of quartz to the melt to reduce erosion at the interface of the crucible and melt surface.

BACKGROUND

[0003] Single crystal silicon ingots may be prepared by the so-called Czochralski method in which a single crystal seed is contacted with a silicon melt held within a crucible. The ~~seed~~ crystal seed is withdrawn from the melt to pull the single crystal silicon ingot from the melt. High or ultra-high resistivity applications may use a crucible which includes a synthetic quartz liner to reduce introduction of impurities into the melt. High or ultra-high resistivity applications are characterized by extended cycle times to allow for dopant compensation. This can cause erosion through the synthetic liner which exposes the quartz base causing impurities to enter the melt thereby lowering the resistivity of the ingot.

from one or more heating elements. The ingot puller apparatus 100 includes bottom insulation 110 and side insulation 124 to retain heat in the puller apparatus. In the illustrated embodiment, the ingot puller apparatus 100 includes a bottom heater 126 disposed below the crucible floor 129. The crucible 102 may be moved to be in relatively close proximity to the bottom heater 126 to melt the polycrystalline silicon charged to the crucible 102.

[0024] To form the ingot, the seed crystal 122 is contacted with the surface 111 of the melt 104. The pulling mechanism 114 is operated to pull the seed crystal 122 from the melt 104. Referring now to Figure 2, 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 (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.

[0025] The ingot puller apparatus 100 includes a side heater 135 and a susceptor 106 that encircles the crucible 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 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

positioned in the crucible 102 such that is abuts the crucible sidewall 131 at the surface 111 of the melt (e.g., by migration to the sidewall or being held in place by a securement device that is discussed further below). Quartz 144 dissolves at the surface 111 of the melt 104 at the crucible sidewall 131 which suppresses erosion of the crucible at the crucible-melt surface interface 125. The oxygen that enters the melt from the quartz 144 evaporates as SiO which suppresses oxygen dissolved from the crucible 102 at the crucible-melt surface interface 125.

[0029] In some embodiments, solid-phase quartz 144 added to the melt 104 is synthetic quartz, i.e., quartz that is formed synthetically such as by a hydrothermal process rather than quartz that is processed from sand. Synthetic quartz that may be used includes SUPRASIL from Haraeus (Hanau, Germany) or Type 098 WGY quartz from Momentive Performance Materials (Waterford, NY). Synthetic quartz is generally more chemically pure than quartz components formed from sand. In some embodiments, the synthetic quartz contains 5.0 ppmw or less impurities, 1.0 ppmw or less or even 0.7 ppmw or less impurities (e.g., 0.5 ppmw or less of aluminum and 0.2 ppmw or less of the sum of lithium, sodium, potassium and calcium).

[0030] In some embodiments, the quartz (e.g., synthetic quartz) 144 that is added to the crucible is shaped as a rod, hollow tube, sphere or an irregular shape (e.g., crushed quartz). Quartz rods may be formed by melting synthetic sand and extruding the melt as a rod. The rod may be cut into smaller segments (which may be referred to as “cullets”) that are added to the melt 104. The rods may be acid washed prior to addition to the melt