[0029] Generally, the melt 6 from which the ingot 60 is drawn is formed by loading polycrystalline silicon into a crucible to form an initial silicon charge 27 (Figure 1). In general, an initial charge is between about 10 kilograms and about 200 kilograms of polycrystalline silicon, which may be granular, chunk, chip, or a combination thereof. The mass of the initial charge depends on the desired crystal diameter and hot zone design. Initial charge does not reflect the length of the ingot crystal, because polycrystalline silicon is continuously fed during crystal growth.

[0030] A variety of sources of polycrystalline silicon may be used including, for example, granular polycrystalline silicon produced by thermal decomposition of silane or a halosilane in a fluidized bed reactor or polycrystalline silicon produced in a Siemens reactor. As described below, an array of quartz particles (i.e., which may be referred to herein as quartz or glass particles and is meant to include fused quartz particles) may be added to the initial charge 27 of solid-phase polycrystalline silicon in the outer melt zone 42 or the middle melt zone 32 of the crucible assembly 10 prior to melting the initial charge 27 of polycrystalline silicon (or later if a smaller array is added such as in a system capable of feeding larger chunks of silicon).

[0031] Once polycrystalline silicon (and the array of quartz particles) is added to the crucible assembly 10 to form a charge 27, the charge 27 is heated to a temperature above about the melting temperature of silicon (e.g., about 1412°C) to melt the charge, and thereby form a silicon melt 6 (Figure 3) comprising molten

[0040] The ingot growth apparatus 5 shown in Figures 1-4 and described herein is exemplary and generally any system in which a crystal ingot is prepared by a continuous Czochralski method may be used unless stated otherwise.

[0041] In accordance with embodiments of the present disclosure, before the ingot 60 is grown, an array 31 (Figure 2) of quartz particles is added to the crucible assembly 10. The array 31 may be added to the crucible assembly 10 before heating the polycrystalline silicon 27 to form the silicon melt 6. The array 31 may be positioned on the initial charge 27 of polycrystalline silicon 27 or may be disposed within the charge 27 (e.g., with polycrystalline silicon disposed above and below the charge).

[0042] An example of an array 31 of quartz particles that is disposed in the outer melt zone 42 is shown in Figure 5. The array 31 includes a plurality of quartz particles 33 and a plurality of linking members 37 that connect adjacent quartz particles 33. The linking members 37 may be made of quartz. The array 31 may be made by 3D printing or by any other suitable method. In methods that involve 3D printing, the array may be built upward from the base with the structure being consolidated or fused layer by layer. In the 3D printing method, the deposition head or fusion source may be capable of translating in an x-y plane to effect consolidation to the final or "green" state of the array. Examples of suitable 3D printing methods that may be used include von Witzendorff et al., "Additive Manufacturing of Glass: CO_2-Laser Glass Deposition Printing," Procedia CIRP 74 (2018), 272-275 and Luo et al., "Additive Manufacturing of Glass,"

particles 33 may be shaped as a rod, tube, sphere or have an irregular shape. In some embodiments, the particles have a size (i.e., largest dimension) between 10 µm and 500 mm. The particles may be sized based on scaffold survivability which is dependent on erosion by the melt and the desired conditioning of the melt.

[0047] In some embodiments, the quartz particles 33 of the array 31 have a relatively high surface area. For example, the quartz particles may have a surface area to mass ratio of at least 0.1 cm^2 quartz/grams of quartz or at least 0.5 cm^2 quartz/grams of quartz (e.g., 0.1 cm^2 quartz/grams of quartz to 10 cm^2 quartz/grams of quartz). In some embodiments, the quartz particles 33 of the array 31 have a relatively high surface area relative to the amount of silicon in the crucible such as at least 10 cm^2 quartz/kg of silicon or at least 50 cm^2 quartz/kg of silicon (e.g., 10 cm^2 quartz/kg of silicon to 250 cm^2 quartz/kg of silicon).

[0048] The array 31 may be any size and shape that allows the array to function as described herein. In accordance with some embodiments of the present disclosure, the array 31 of quartz particles may have a sufficient width such that the array 31 continuously extends from the sidewall 40 of the crucible assembly 10 to the first weir 20. In other embodiments, the array 31 has a width less than the distance between the sidewall 40 of the crucible assembly 10 to the first weir 20. In some embodiments, the array 31 has a width between about 50 mm to about 75 mm and/or a height (i.e., depth) between 6 mm and 100 mm.

[0049] An embodiment of a quartz particle 33 for use in an array 31 is shown in Figure 7. The quartz particle 33 is shaped as a hollow sphere having openings 51 formed therein. In the embodiment illustrated in Figure 8, the quartz particles 33 include spires which extend from a core of the structure. In the embodiment illustrated in Figure 9, the quartz particles include dimples which increase the surface area of the particle 33.

[0050] The array 31 may be less dense than the melt 6 which allows the array 31 to float on the melt with a portion of the array 31 being disposed above the melt 6. In other embodiments, the array 31 may have a density more similar to the melt such that the array 31 is immersed (or partially immersed) in the melt 6.

[0051] In some continuous Czochralski processes, more than one ingot is grown while the hot zone (i.e., lower portion of the apparatus 5 such as the crucible assembly 10 and the susceptor 13) remains heated with silicon melt 6 being continuously within the crucible assembly 10. In such methods, a first ingot is grown to a target length and growth is terminated, the ingot is removed from the ingot puller, and a seed crystal is then lowered into the melt to initiate growth of a second single crystal silicon ingot (i.e., using the same melt from which the first ingot was withdrawn). Subsequent ingots may be grown with the hot zone intact and at temperature with a continuous melt of silicon being within the crucible assembly 10 (e.g., until one or more components of the hot zone have degraded such as the crucible assembly requiring cool-down and replacement of the degraded component). For example, at least 1, 2, 3, 4, 5, 6, 10, or 20 or more