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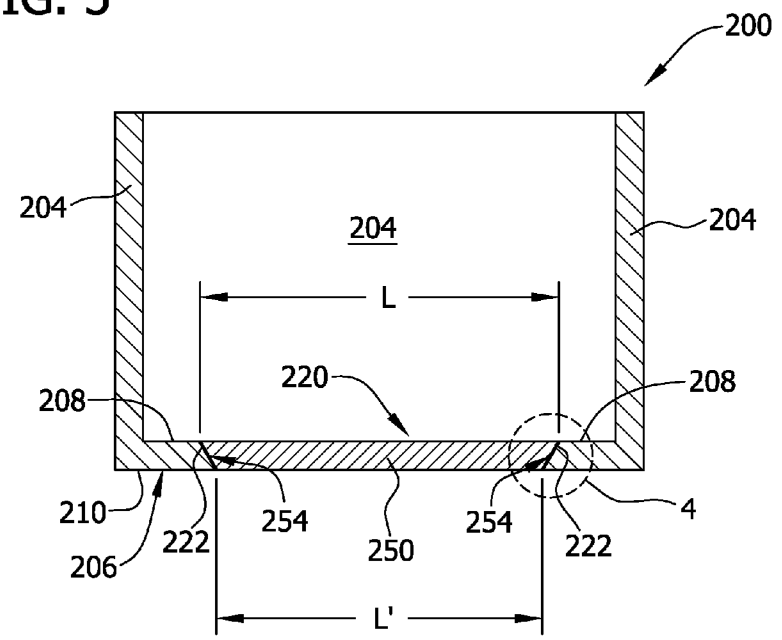
[Continued on next page]

(54) **Title**: CRUCIBLE FOR USE IN A DIRECTIONAL SOLIDIFICATION FURNACE

FIG. 3



(57) **Abstract**: A directional solidification furnace comprises a crucible assembly including a crucible for containing a melt having walls and a base with an opening therein, a crucible support for supporting the crucible, and a lid covering the crucible. A plate is received in the opening in the base. The plate has a higher thermal conductivity than that of the base. The base can include a composite having an additive such that the composite base has a higher thermal conductivity than a comparable without the additive.

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CRUCIBLE FOR USE IN A DIRECTIONAL SOLIDIFICATION FURNACE

BACKGROUND

[001] This invention generally relates to directional solidification furnaces and, more specifically, to a directional solidification furnace for improving the solidification rate.

[002] Directional solidification furnaces, such as those shown in Figure 1 and referred to generally at 100, are often used in the production of multi-crystalline silicon ingots. The directional solidification furnace 100 of Figure 1 comprises a crucible 102 supported by a crucible support 103 having graphite support walls that add structural rigidity to the crucible. The crucible 102 includes walls 104 (crucible support walls) and a base 106. The crucible 102 is typically constructed of quartz, or another suitable material that can withstand high temperatures while remaining essentially inert.

[003] Together with a lid 112, the crucible 102 and crucible support 103 form an inner assembly 105. This inner assembly 105 may also include a heat exchanger 107 disposed beneath the base 106. Heaters 108 are positioned around the walls 104 and within a containment vessel 110. The heaters 108 may suitably be radiant heaters configured to apply the heat necessary to melt charge material within the crucible. The charge material of this embodiment is silicon, though other materials are contemplated.

[004] Side insulation 109 is disposed around the crucible and may be partially opened, such as by vertical movement. Once the silicon charge has melted, a cooling medium may be introduced to the heat exchanger 107 and/or the insulation 109 may be raised to aid in the directional solidification of the silicon. The heat output of the heaters 108 may be adjusted so that less heat is applied to the melt 111. The position of the heaters 108 may also be adjusted relative to the crucible by moving them away from the crucible 102, especially away from the crucible base 106.

[005] After the crucible 102 has been charged with silicon, the area surrounding the crucible is sealed from the outside ambient environment. To aid in the separation of the crucible 102 from the outside environment, the crucible is placed within the containment vessel 110 that forms part of the furnace. The pressure within the containment vessel 110 is then reduced. The content of the atmosphere within the containment vessel 110 can also be monitored and controlled.

[006] The crucible 102 and the charge are then heated to a temperature sufficient to melt the silicon. After the charge has completely melted it is cooled at a controlled rate to achieve a directional solidification structure. The controlled rate of cooling is established by any combination of reducing the amount and location of heat applied by the heaters 108, the movement of or the opening of a heat vent in insulation 109 surrounding the crucible 102, or the circulation of a cooling medium through the heat exchanger 107 (e.g., a cooling plate). Any of these methods transfer heat away

from the surface of the crucible 102. If the rate of cooling of the base 106 of the crucible 102 is greater than that of the walls 104 of the crucible, then a relatively flat, horizontal solidification isotherm with predominately axial thermal gradients is generated. The ingot thereby solidifies in the region closest to the cooler side of the crucible 102 and proceeds in a direction away from that side of the crucible. The last portion of the melt 111 to solidify is generally at the top of the ingot.

[007] A significant concern in the production of multi-crystalline silicon ingots in directional solidification furnaces is the amount of time required to generate an ingot from raw silicon. The rate at which the ingot solidifies directly affects the amount of time required to form the ingot from the raw materials.

[008] This Background section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

BRIEF SUMMARY

[009] A first aspect of the disclosure is a directional solidification furnace comprising a crucible assembly. The crucible assembly includes a crucible for

containing a melt, the crucible including walls and a base, the base having an opening therein. A crucible support supports the crucible and a lid covers the crucible. A plate is received in the opening in the base. The plate has a higher thermal conductivity than that of the base.

[0010] Another aspect of the disclosure is a directional solidification furnace comprising a crucible assembly. The crucible assembly includes a crucible for containing a melt, the crucible including walls and a composite base. A crucible support supports the crucible and a lid covers the crucible. The composite base includes an additive such that the composite base has a higher thermal conductivity than a comparable base without the additive.

[0011] Yet another aspect of the disclosure is a method of producing an ingot in a directional solidification furnace. The method comprises melting a silicon charge in a crucible of the furnace to form a liquid melt. The crucible includes a base having a first portion and a second portion. The first portion has a higher thermal conductivity than the second portion. Heat is then transferred from the melt through the base of the crucible. Heat is transferred through the first portion of the base at an increased rate compared to the second portion. The transfer of heat from the melt results in the solidification of the melt and production of the ingot.

[0012] Various refinements exist of the features noted in relation to the above-mentioned aspects.

Further features may also be incorporated in the above-mentioned aspects as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to any of the illustrated embodiments may be incorporated into any of the above-described aspects, alone or in any combination.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Figure 1 is a partially schematic cross-section of a known directional solidification furnace;

[0014] Figure 2 is a top plan view of a first embodiment of a crucible for use in the directional solidification furnace of Figure 1;

[0015] Figure 3 is a cross-section of the crucible of Figure 2 taken along line 3-3 in Figure 2;

[0016] Figure 4 is an enlarged portion of Figure 3;

[0017] Figure 5 is a top plan view of a second embodiment of a crucible for use in the directional solidification furnace of Figure 1;

[0018] Figure 6 is a cross-section of the crucible of Figure 5 taken along line 6-6 in Figure 5;

[0019] Figure 7 is a top plan view of a third embodiment of a crucible for use in the directional solidification furnace of Figure 1;

[0020] Figure 8 is a cross-section of the crucible of Figure 7 taken along line 8-8 in Figure 7;

[0021] Figure 9 is a top plan view of a fourth embodiment of a crucible for use in the directional solidification furnace of Figure 1;

[0022] Figure 10 is a cross-section of the crucible of Figure 9 taken along line 10-10 of Figure 9;

[0023] Figure 11 is an enlarged portion of Figure 10; and

[0024] Figure 12 is a flow diagram depicting a method of producing an ingot in a directional solidification furnace using any of the crucibles shown in Figures 2 – 11.

[0025] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0026] Figures 2, 3, and 4 show respective top plan, cross-sectional, and enlarged views of a first embodiment of a crucible 200 for use in any directional solidification furnace, such as the furnace 100 shown in Figure 1. The crucible 200 has a base 206 (generally, a "second portion") and four walls 204 extending upward from the base. The base 206 and walls 204 may be integrally formed together or joined together such that the melt 111 (Figure 1) is contained therein. The base 206 has an upper surface 208 and a lower surface 210 and an opening 220 extending between the upper and lower surfaces.

[0027] The opening 220 is defined by a void formed in the crucible 200 that is bounded by four sides 222. In other embodiments, the opening 220 may be a shape other than rectangular, such as circular, oval, or any other suitable shape and the plate 250 placed therein is shaped accordingly. The opening 220 may be formed in the crucible 200 by machining or otherwise removing a section of base 206. In other embodiments, the opening 220 may be formed during manufacture of the crucible 200.

[0028] The opening 220 has a length L and a width W adjacent the upper surface 208 of the base 206 and a length L′ and a width W′ adjacent the lower surface 210. Each of the sides 222 slopes inward away from the walls 204 of the crucible 200 such that the length L is greater than the length L′ and the width W is greater than the width W′. In some embodiments, the length L, length L′, width W, and width W′ may be between 50mm and 630mm. As more clearly seen in Figure 4, the sides 222 are angled at approximately 45 degrees with respect to the lower surface 210 of the base 206. However, the sides 222 may be oriented at a different angle without departing from the scope of the embodiments. For example, in some embodiments, the sides 222 may be oriented at approximately 35 degrees with respect to the lower surface 210 of the base 206.

[0029] A plate 250 (generally, a “first portion”) having four sides 252 is sized for positioning within the opening 220. While the embodiments herein disclose placing the plate 250 in the base 206 of the crucible 200, additional plates may be placed within any or all of the walls 204. Moreover, in some embodiments the plate 250 may not be used, and instead plates similar to the plate 250 may be placed within any or all of the walls 204.

[0030] The plate 250 is formed from a material having a higher thermal conductivity than the base 206 of the crucible 200. In one embodiment, the plate 250 may be formed from fused quartz. In some embodiments, the plate 250 has a thermal conductivity (k) that is approximately 3 $\frac{W}{m\ °K}$ compared to a typical thermal conductivity of the base 206 of 1 $\frac{W}{m\ °K}$. In other embodiments, the plate 250 is formed from any material having a thermal conductivity greater than the base 206 of the crucible 200 that has a higher melting point than the melt 111. For example, the plate 250 may be formed from MgO, AlN, SiC, graphite, or a composite of MgO and SiC. According to some embodiments, the plate 250 may only be used one time, after which it is removed and repaired or discarded. In other embodiments, the plate 250 is used multiple times before removal.

[0031] The plate 250 has a thickness T_1 that is substantially the same as a thickness T_2 of the base 206 of the crucible 200 adjacent the plate 250. In some embodiments, T_1 may be equal to between 5mm and 25 mm and T_2 may be equal to between 5mm and 25mm. In other embodiments, the thickness T_1 of the plate 250 may be greater or less than the thickness T_2 of the base 206. As seen in Figure 4, the plate 250 has four sides 252 with a sloped profile that corresponds to the sides 222 of the opening 220 such that the plate is in registry with the sides of the opening. The sloped sides 222 of the opening form a first angle that is complementary a second angle formed by the sloped profile of the four sides 252 of the plate 250. The geometry of the sides 222 of the opening 220 and the sides 252 of the plate 250 thus result in the weight of the melt 111 pressing the sides of the plate against the sides of the opening. A bonding agent may be used to further secure the plate 250 within the sides 222 of the opening 220 such that the melt 111 is not able to pass between opening and the plate.

[0032] In some embodiments, the bonding agent is a slip cast silica compound 256. The size of the joint 254 and amount of slip cast silica compound 256 contained therein shown in Figure 4 is greatly exaggerated for illustration. Prior to use of the crucible 200, a joint 254 between the plate 250 and the lower surface 210 of the base 206 may be sealed with tape or other material. Slip cast silica 256 in a fluid state is the poured into the joint 254 adjacent the upper surface 208 of the base 206. The solvent in the fluid slip cast silica 256 then evaporates, and the silica remains as a joint filler. The crucible 200 may then be fired to cure the slip cast silica 256 in the joint 254.

[0033] Figures 5 and 6 show respective top plan and cross-sectional views of a second embodiment of a crucible 300 for use in any directional solidification furnace, such as the furnace 100 shown in Figure 1. The crucible 300 has a base 306 (generally, a “second portion”) and four walls 304 extending upward from the base. The base 306 and walls 304 may be integrally formed together or joined together such that the melt 111 (Figure 1) is contained therein. The base 306 has an upper surface 308 and a lower surface 310. A recess 320 extends upward from the lower surface 310 towards the upper surface 308, but does not pass through the upper surface 308 of the base 306.

[0034] A plate 350 (generally, a "first portion") having four sides 352 is sized for positioning within the recess 320. In other embodiments, the recess 320 and plate 250 may not be rectangular, and instead be circular, oblong, or any other suitable shape. While the embodiments herein disclose placing the plate 350 in the recess 320 in the base 306 of the crucible 300, additional plates may be placed within any or all of the walls 304. Moreover, the plate 350 may not be used, and instead plates may be placed within any or all of the walls 304.

[0035] A portion 360 of the base 306 separates the plate 350 from the melt disposed in the crucible. The portion 360 prevents the melt from damaging, wearing, or corroding the plate 350. According to some embodiments the portion 360 may have a thickness $T_{PORTION}$ between 1mm and 20mm while the plate 350 may have a thickness T_{PLATE} between 1mm and 20mm and the base 306 may have a thickness T_{BASE} between 1mm and 20mm. Moreover, while the thicknesses of the plate T_{PLATE} and portion $T_{PORTION}$ are shown as being uniform, the thicknesses may vary. As the plate 350 is shielded from the melt 111 by the portion 360 of the base 306, the plate may thus be used multiple times before replacement.

[0036] The plate 350 is attached to the base 306 by any bonding mechanism, such as adhesive or fasteners. In some embodiments, slip cast silica is used to fasten the plate 360 to the recess 320. In other embodiments, a friction fit between the recess 320 and the plate 350 retains the plate in the recess.

[0037] The plate 350 is formed from a material having a higher thermal conductivity than the base 306 of the crucible 300. In one embodiment, the plate 350 may be formed from fused quartz. In these embodiments the plate 250 and the portion 360 of the base 306 have a combined effective thermal conductivity (k_{eff}) that is up to approximately 10 $\frac{W}{m\,°K}$ compared to a typical thermal conductivity of the base 306 of 1 $\frac{W}{m\,°K}$.

[0038] In other embodiments, the plate 350 is formed from any material having a thermal conductivity greater than the base 306 of the crucible 300. For example, the plate 350 may be formed from MgO, AlN, SiC, graphite, or composites of MgO and SiC, SiO_2 and AlN, SiO_2 and MgO, and SiO_2 and TiO_2. Moreover, as the plate 350 is shielded from the melt 111 by the portion 360, materials that would otherwise not be suitable for contact with the melt may be used in its construction (e.g., TiO_2).

[0039] Table 1

T_{BASE}	$T_{PORTION}$	T_{PLATE}	$k_{PORTION}$	k_{PLATE}	k_{eff}
20	5	15	1	3	2
20	10	10	1	3	1.5
20	15	5	1	3	1.2
20	5	15	1	50	3.77
20	10	10	1	50	1.96
20	15	5	1	50	1.32
20	2	18	1	50	8.47

[0040] As shown in Table 1 above, the effective thermal conductivity (k_{eff}) of the base 306 is dependent on the thermal conductivities of the portion 360

($k_{PORTION}$) and the plate 350 (k_{PLATE}) and their thicknesses, $T_{PORTION}$ and T_{PLATE}. The combined effective thermal conductivity (k_{eff}) of the plate 350 and the portion 360 is dependent on the composition of the plate and the thicknesses of the plate and the portion. The combined thermal conductivity (K_{eff}) of the base 206 is expressed as: $k_{eff} \equiv \frac{T_{BASE}}{\left(\frac{T_{PLATE}}{k_{PLATE}} + \frac{T_{PORTION}}{k_{PORTION}}\right)}$.

[0041] Figures 7 and 8 show respective top plan and cross-sectional views of a third embodiment of a crucible 400 for use in any directional solidification furnace, such as the furnace 100 shown in Figure 1. The crucible 400 has a base 406 (generally, a "second portion") and four walls 404 extending upward from the base. The base 406 and walls 404 may be integrally formed together or joined together such that the melt 111 (Figure 1) is contained therein. The base 406 has an upper surface 408 and a lower surface 410.

[0042] The base 406 has a portion 450 (generally, a "first portion") of increased thermal conductivity. While the embodiments herein disclose placing the portion 450 in the base 406 of the crucible 400, additional portions may be placed within any or all of the walls 404. Moreover, the portion 450 may not be used, and instead portions of increased thermal conductivity are placed within any or all of the walls 404.

[0043] The portion 450 includes one or more additive materials 452 that are intermixed with the material from which the base 406 is formed to form a composite. The number of additive materials 452 shown in Figure 7 is greatly reduced for the sake of clarity and the relative size of the additive materials is likewise greatly increased for clarity. The additive materials 452 have a greater thermal conductivity than the material from which the base 406 is formed. The thermal conductivity of the portion 450 of the base 406 having the increased thermal conductivity is thus generally in the range of three to ten times greater than that of the remainder of the base and the walls 404 of the crucible 400. The additive materials 452 in the portion 450 may be selected from any material that is capable of being intermixed with the material from which the base 406 is formed during construction of the base. For example, the additive materials 452 may be any one of or a combination of MgO, SiC, AlN, or TiO_2.

[0044] Figures 9, 10, and 11 show respective top plan, cross-sectional, and enlarged views of a fourth embodiment of a crucible 500 for use in any directional solidification furnace, such as the furnace 100 shown in Figure 1. The crucible 500 has a base 506 (generally, a "second portion") and four walls 504 extending upward from the base. The base 506 and walls 504 may be integrally formed together or joined together such that the melt 111 (Figure 1) is contained therein. The base 506 has an upper surface 508 and a lower surface 510. An opening 520 extends between the upper surface 508 and the lower surface 510.

[0045] The opening 520 is defined by a void formed in the crucible 500 that is bounded by four sides

522. The opening 520 may be formed in the crucible 500 by machining or otherwise removing a section of base 506. In other embodiments, the opening 520 may be formed during manufacture of the crucible 500 such that a section of the base is not removed to form the opening.

[0046] A portion 530 of the base 506 extends inward from the sides 522 of the opening 520 and away from the walls 504. The portion 530 has a thickness T_3, measured from the bottom surface 510, which is less than a thickness T_4 of the base 506. The portion 530 thus extends out from the base 506 and forms a ledge structure.

[0047] A plate 550 (generally, a "first portion") is sized for placement within the opening 520. In other embodiments, the opening 520 and plate 550 may not be rectangular, and instead be circular, oblong, or any other suitable shape. While the embodiments herein disclose placing the plate 550 in the base 506 of the crucible 500, additional plates may be placed within any or all of the walls 504. Moreover, plate 550 may not be used, and instead plates may be placed within any or all of the walls 504.

[0048] The plate 550 is formed from a material having a higher thermal conductivity than the base 506 of the crucible 500. In one embodiment, the plate 550 may be formed from fused quartz. In some embodiments, the plate 550 has a thermal conductivity (k) that is approximately $3\frac{W}{m * {}^{o}K}$ compared to a typical thermal conductivity of the base 506 of $1\frac{W}{m * {}^{o}K}$. In other embodiments, the plate 550 is formed from any material having a thermal conductivity greater than the base 506 of the crucible 500 that has a higher melting point than the melt 111. For example, the plate 550 may be formed from MgO, AlN, SiC, graphite, or a composite of MgO and SiC.

[0049] The plate 550 has a lip portion 552 extending outward from the remainder of the plate along its circumference. The lip portion has a width W1 approximately equal to a width W2 of the portion 530 extending from the sides 522 of the base 506. During use, the lip portion 552 is positioned directly above the portion 530 of the base 506. The lip portion 552 and portion 530 of the base 506 thus together form a lap joint. The lap joint of the plate 550 and base 506 thus result in the weight of the melt 111 pressing the plate into contact with the base. A bonding agent may be used to further secure the plate 550 within the opening 520 such that the melt 111 is not able to pass between the opening and the plate. In some embodiments, the bonding agent is a slip cast silica compound 556. Prior to use of the crucible 500, a joint 554 between the plate 550 and the lower surface 510 of the base 506 may be sealed with tape or other material. Slip cast silica 556 in a fluid state is the poured into the joint 554 adjacent the upper surface 508 of the base 506. The solvent in the fluid slip cast silica 556 then evaporates, and the silica remains as a joint filler. The crucible 500 may then be fired to cure the slip cast silica 556 in the joint 554.

[0050] The increased thermal conductivity of the bases of the crucibles described above in Figures 2 through 11 results in an increased thermal flux (i.e., flow of thermal energy) through the respective bases. The increased heat flux through the base of the crucible results in an increase in the solidification rate of the melt contained within the crucible. In some embodiments, the solidification rate may increase by two to three times that shown in conventional crucibles.

[0051] The increase in the solidification rate of the melt thus reduces the amount of time required for the melt to cool and form the solidified ingot. The reduction in the amount of time required to form the melt increases the rate (i.e., throughput) at which ingots can be produced in directional solidification furnaces using crucibles like those described above.

[0052] Figure 12 depicts an exemplary method 600 for producing an ingot in a directional solidification furnace using any of the crucibles shown in Figures 2 – 11. As described above, the furnace includes a crucible having a base with a first portion (e.g., the plate 250, the plate 350, the portion 450, or the plate 550) and a second portion (e.g., the base 206, the base 306, the base 406, or the base 506). The first portion has a higher thermal conductivity than the second portion. In the exemplary embodiment, the first portion has a thermal conductivity that is at least double that of the second portion.

[0053] The crucible is first loaded with a silicon charge. The method 600 then begins in block 610 with the melting of the silicon charge to form a liquid melt. In block 620, heat is transferred from the melt through at least the base of the crucible. Heat is transferred through the first portion at an increased rate compared to the rate at which it is transferred through the second portion. The transfer of heat from the melt solidifies the melt into an ingot.

[0054] While the invention has been described in terms of various specific embodiments, it will be recognized that the invention can be practiced with modification within the spirit and scope of the claims.

[0055] When introducing elements of the present disclosure or the embodiments thereof, the articles "a", "an", "the" and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. The use of terms indicating a particular orientation (e.g., "top", "bottom", "side", etc.) is for convenience of description and does not require any particular orientation of the item described.

[0056] As various changes could be made in the above constructions and methods without departing from the scope of the disclosure, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A directional solidification furnace comprises:

a crucible assembly including:

a crucible for containing a melt, the crucible including walls and a base, the base having an opening therein;

a crucible support supporting the crucible,

a lid covering the crucible; and

a plate received in the opening in the base, the plate having a higher thermal conductivity than that of the base.

2. The directional solidification furnace of claim 1 wherein the opening extends through the base, the opening having sloped walls of a first angle and the plate having sloped walls of a second angle complementary to the first angle.

3. The directional solidification furnace of claim 1 wherein the opening extends through the base, the opening defined by a void in the base having four sides, a portion of the base extending inward from the sides to form a ledge structure.

4. The directional solidification furnace of claim 1 wherein the plate has a thickness that is substantially equal to a thickness of the base.

5. The directional solidification furnace of claim 1 wherein the plate is secured to the base by a bonding agent.

6. The directional solidification furnace of claim 1 wherein the plate has a thermal conductivity at least twice that of the base.

7. The directional solidification furnace of claim 1 further comprising:

a heat exchanger disposed beneath the base of the crucible support.

8. The directional solidification furnace of claim 1 wherein the crucible is made of graphite.

9. The directional solidification furnace of claim 1 further comprising:

one or more movable heaters removably disposed around the crucible support.

10. The directional solidification furnace of claim 1 further comprising:

removable insulation disposed around the crucible.

11. The directional solidification furnace of claim 1 wherein the crucible walls include four walls joined together such that the liquid melt is contained therein.

12. The directional solidification furnace of claim 1 wherein the base has an upper surface and a lower surface, the opening not extending through the base, the opening disposed in the lower surface and forming a portion of a recess in the lower surface.

13. The directional solidification furnace of claim 12 wherein the plate is disposed in the recess and is separated from the melt in the crucible by the base.

14. A directional solidification furnace comprises:

a crucible assembly including:

a crucible for containing a melt, the crucible including walls and a composite base;

a crucible support supporting the crucible,

a lid covering the crucible; and

the composite base including an additive such that the composite base has a higher thermal conductivity than a comparable base without the additive.

15. The directional solidification furnace of claim 14 wherein the additive is selected from the group comprising: MgO, SiC, AIN and TiO_2.

16. The directional solidification furnace of claim 14 wherein at least a portion of the crucible walls include the additive such that the portion of the crucible walls has a higher thermal conductivity than a portion of the wall without the additive.

17. The directional solidification furnace of claim 16 wherein the additive is selected from the group comprising: MgO, SiC, AIN and TiO_2.

18. A method of producing an ingot in a directional solidification furnace comprising:

melting a silicon charge in a crucible of the furnace to form a liquid melt, the crucible including a base, at least a first portion of the base having a higher thermal conductivity than a second portion of the base; and

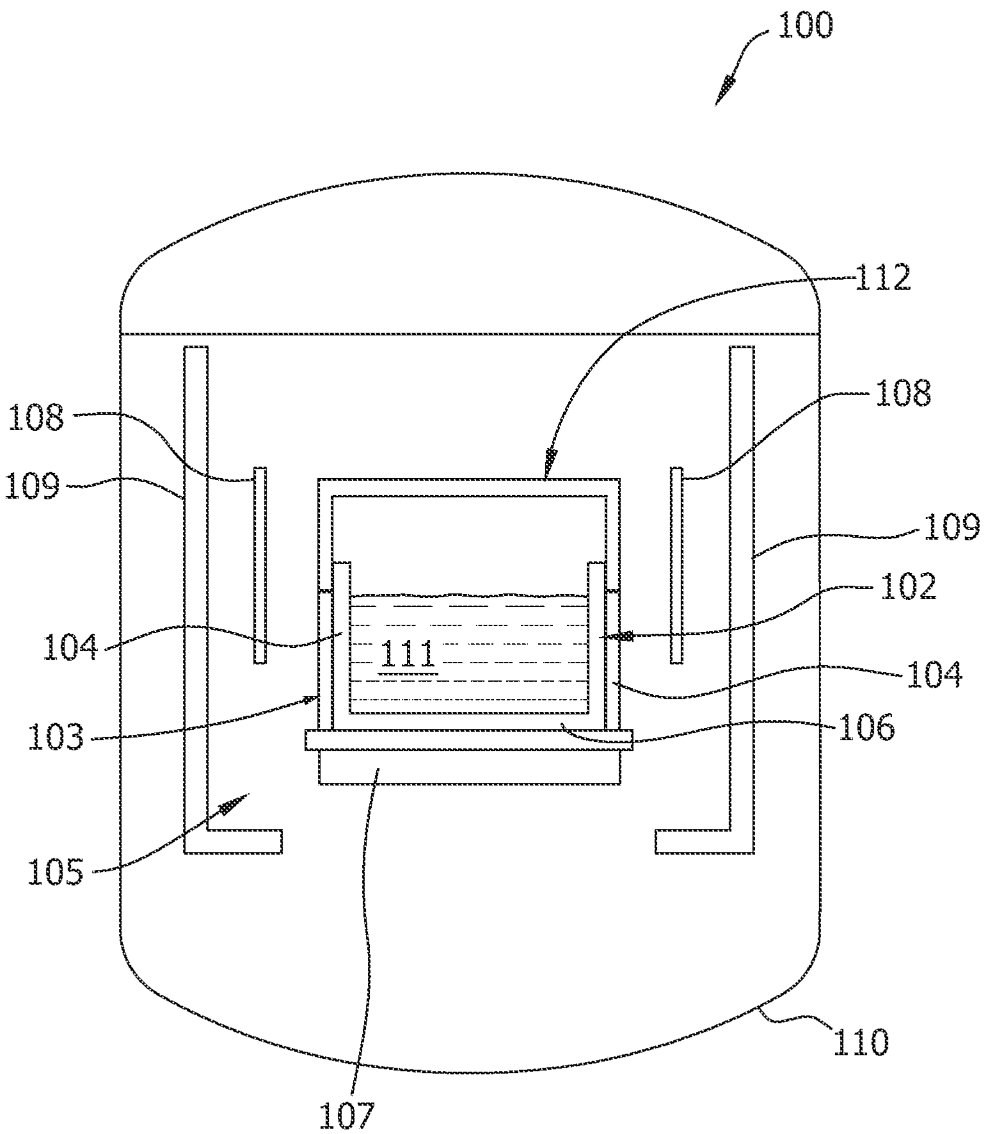
transferring heat from the melt through at least the base of the crucible, wherein heat is transferred through the first portion of the base at an increased rate compared to the second portion,

wherein the transfer of heat from the melt results in the solidification of the melt and production of the ingot.

19. The method of claim 17 further comprising, prior to melting the silicon charge, loading the crucible with the silicon charge.

20. The method of claim 17 wherein heat is transferred through the first portion of the base having a thermal conductivity at least double that of the second portion of the base.

FIG. 1



PRIOR ART

FIG. 2

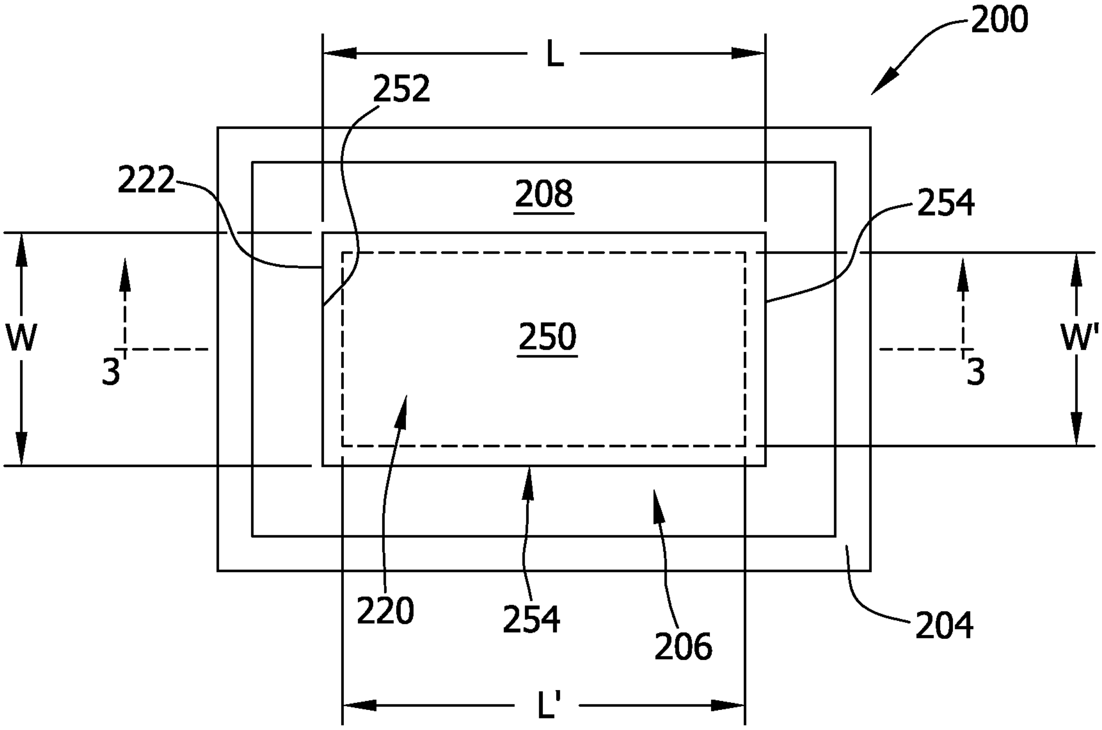

200
L
252
222
208
254
W
3
250
3
W'
220
254
206
204
L'

FIG. 3

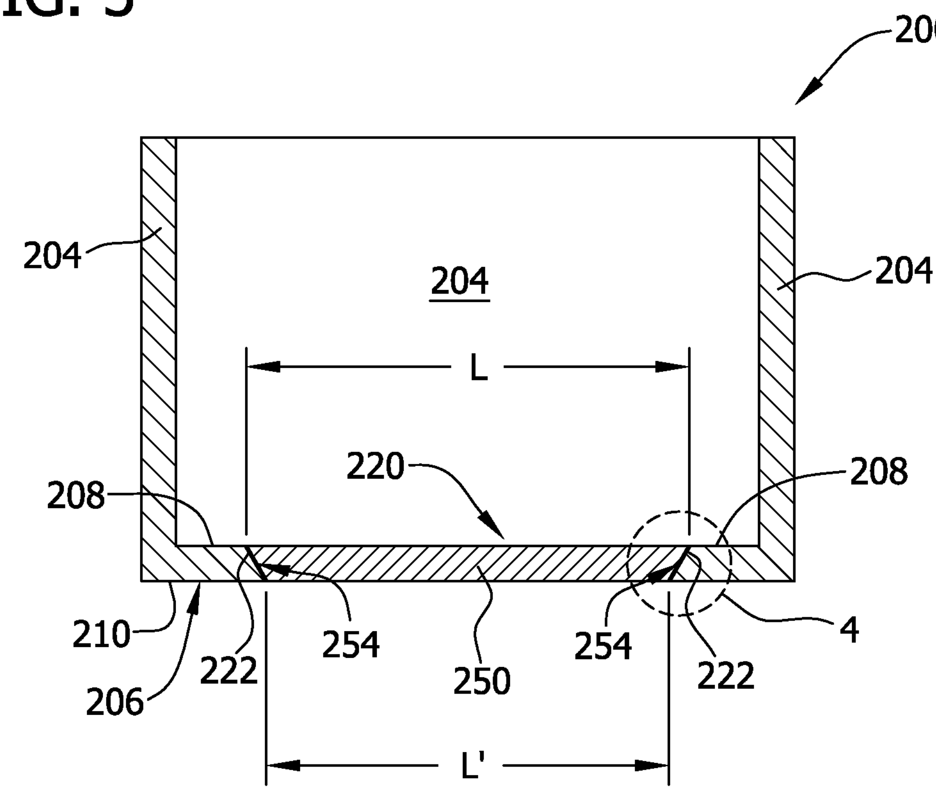

200
204
204
204
L
220
208
208
210
222
254
250
254
222
4
206
L'

FIG. 4

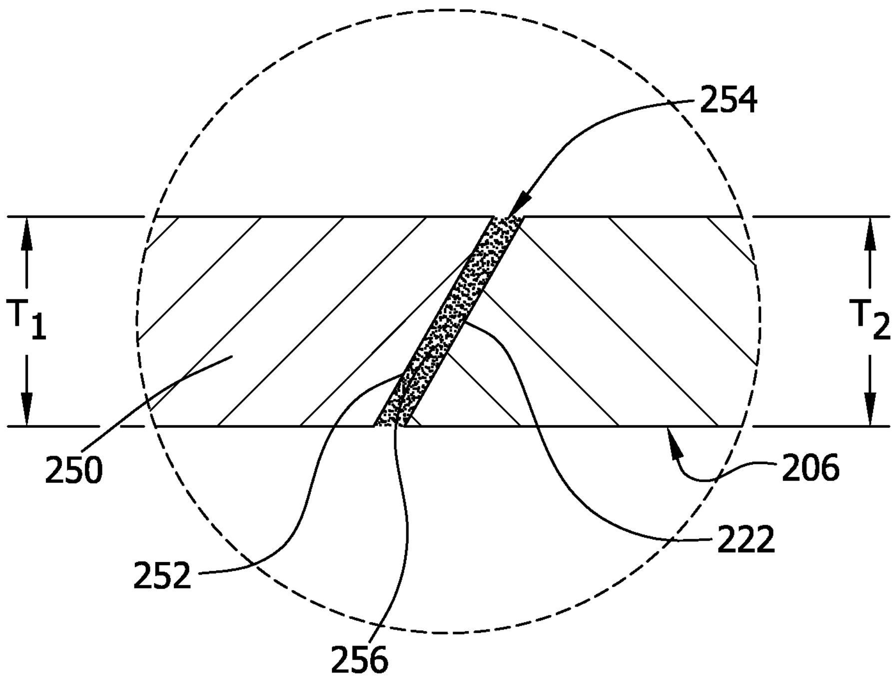
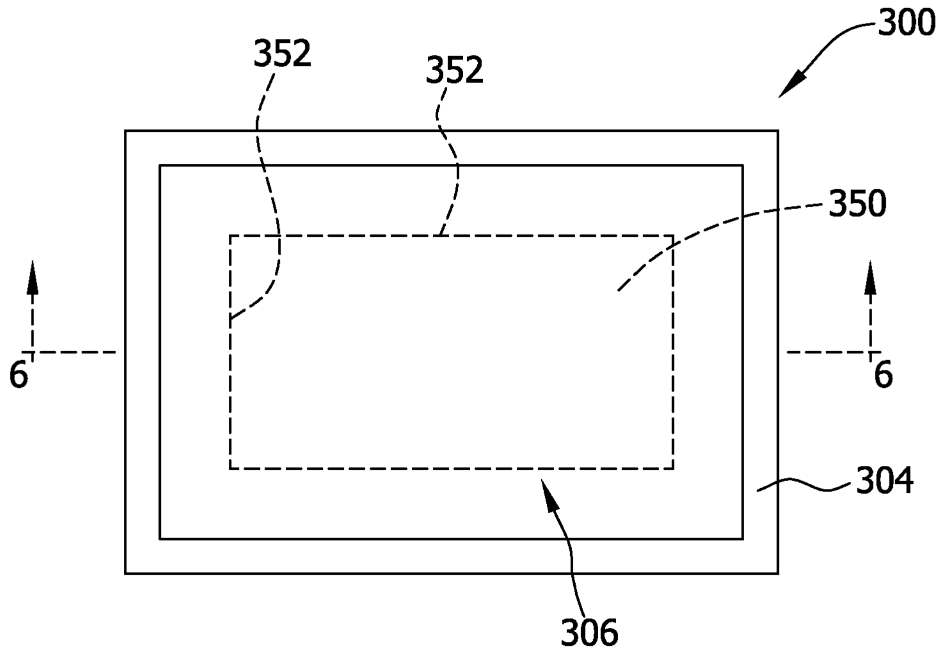


FIG. 5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352
352
350
6
6
304
306

FIG. 6

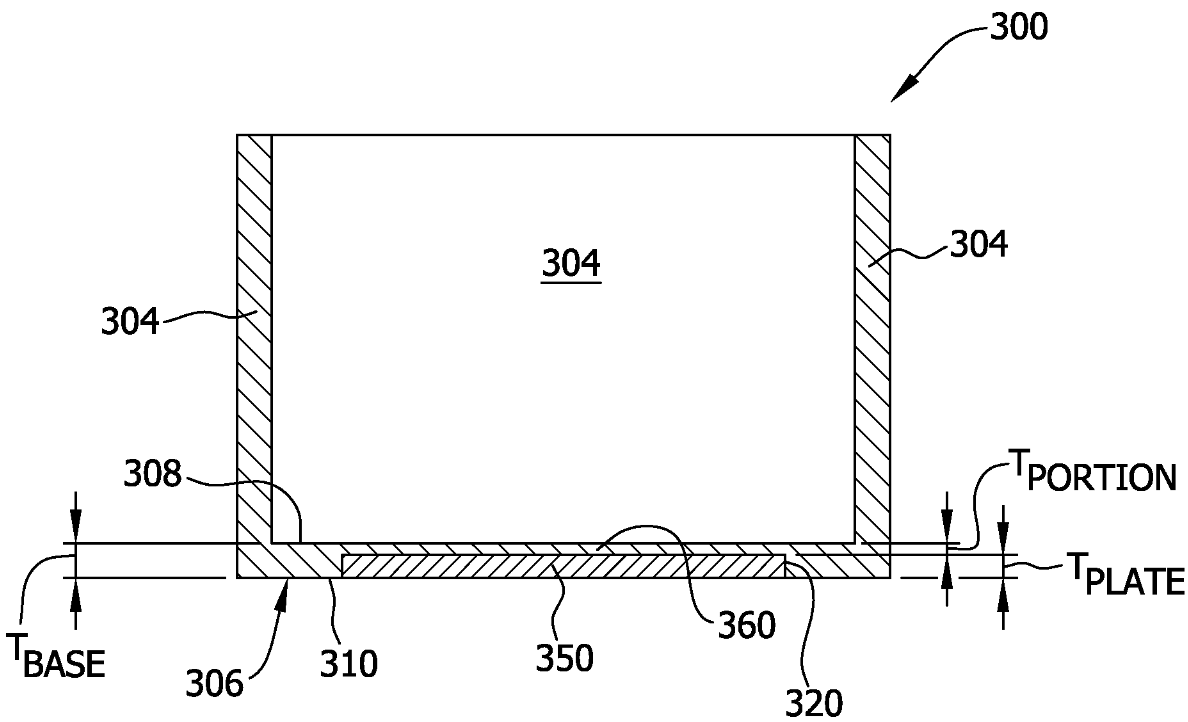

300
304
304
304
308
$T_{PORTION}$
T_{PLATE}
T_{BASE}
306
310
350
360
320

FIG. 7

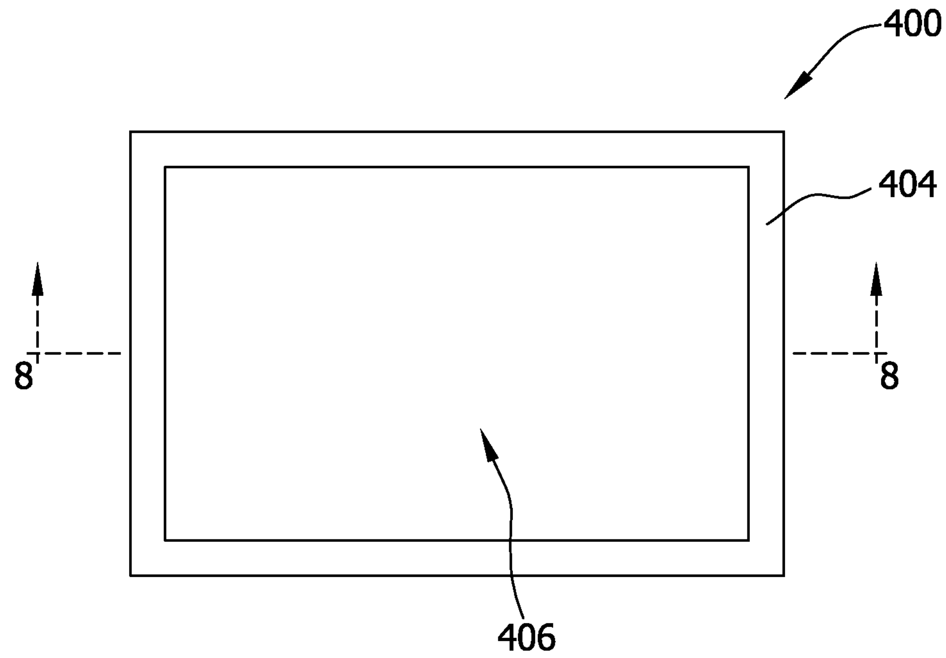


FIG. 8

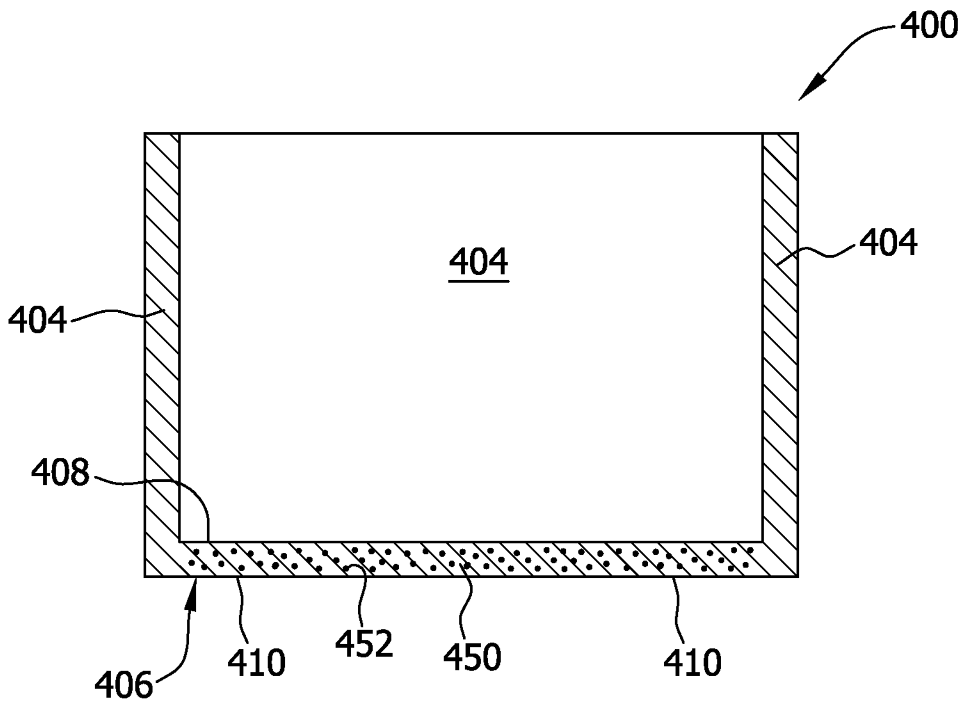


FIG. 9

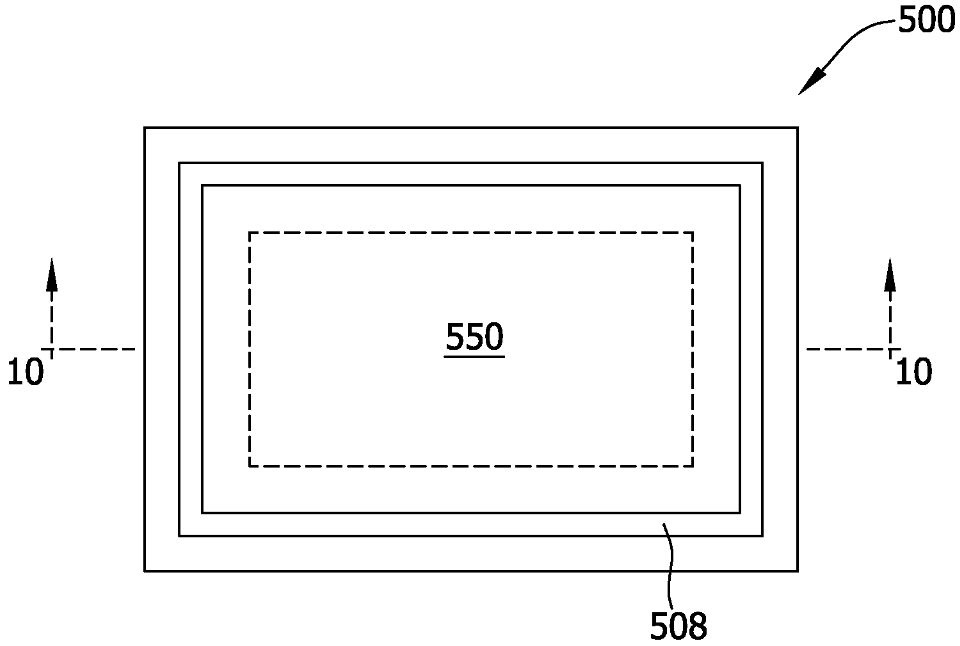
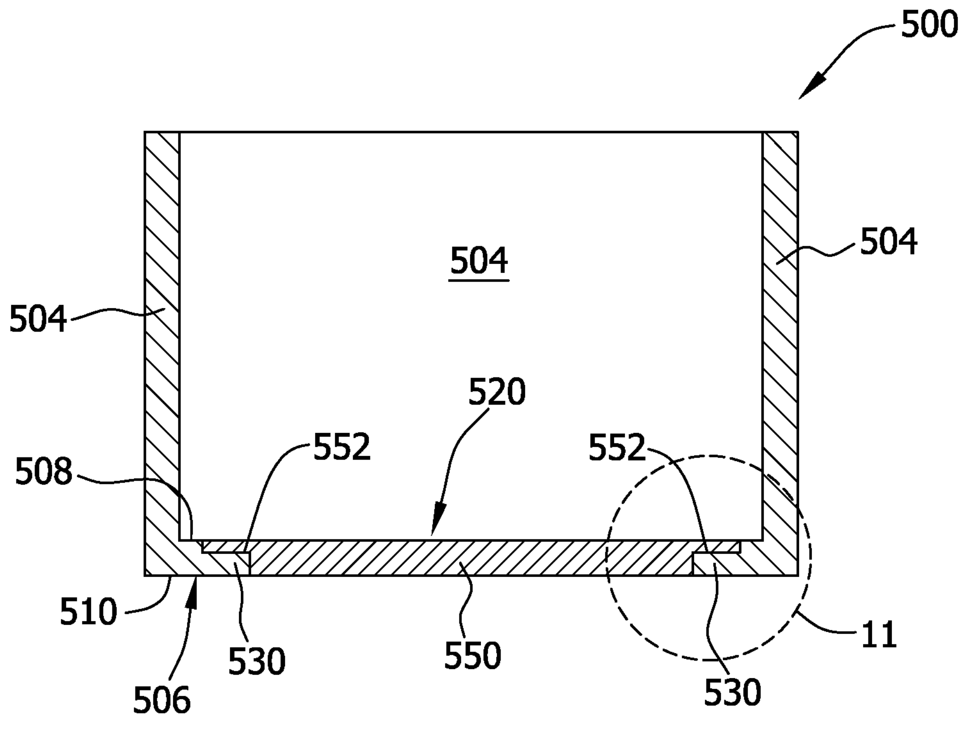

500
550
10
10
508

FIG. 10


500
504
504
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520
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510
506
530
550
530
11

FIG. 11

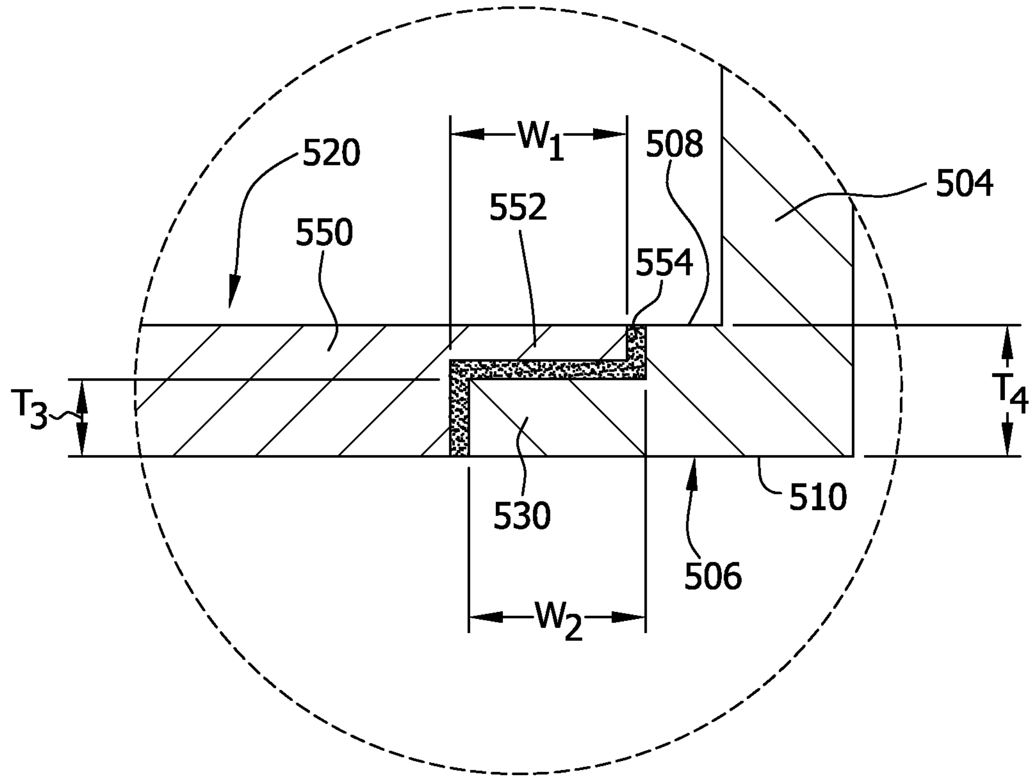
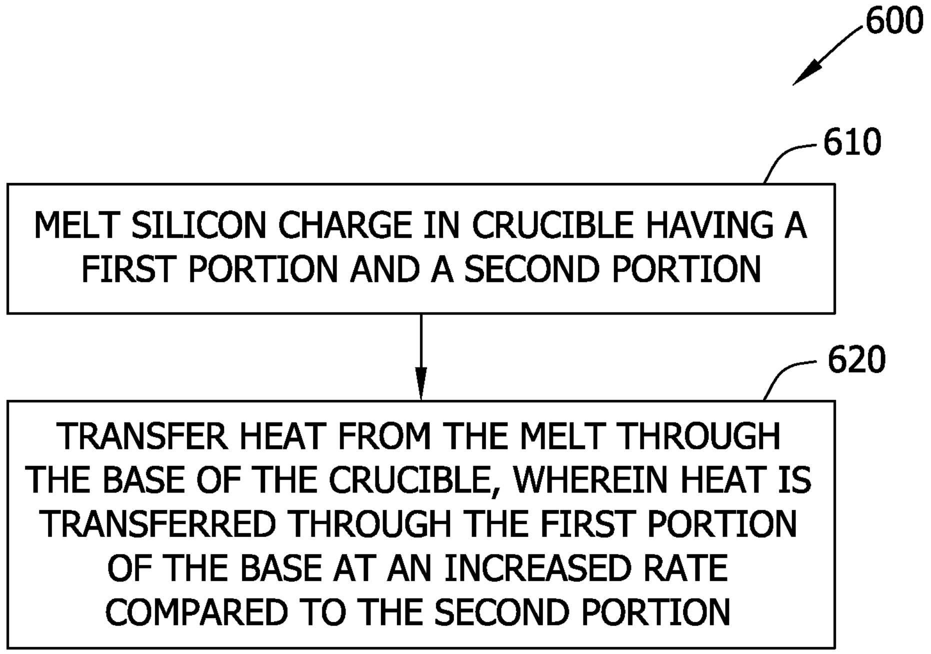


FIG. 12


600
610
MELT SILICON CHARGE IN CRUCIBLE HAVING A FIRST PORTION AND A SECOND PORTION
620
TRANSFER HEAT FROM THE MELT THROUGH THE BASE OF THE CRUCIBLE, WHEREIN HEAT IS TRANSFERRED THROUGH THE FIRST PORTION OF THE BASE AT AN INCREASED RATE COMPARED TO THE SECOND PORTION

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/050392

A. CLASSIFICATION OF SUBJECT MATTER
INV. C30B11/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C30B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	GB 2 084 978 A (CRYSTAL SYST) 21 April 1982 (1982-04-21) abstract; figure 1 page 1, lines 118-129 page 2, lines 1-8,14-19,28-30,46-50	1,5-7, 18-20 14-17
X	DE 42 36 827 A1 (WACKER CHEMITRONIC [DE]; FRAUNHOFER GES FORSCHUNG [DE]) 5 May 1994 (1994-05-05) column 2, lines 54-56, 64-68; figure 1 column 3, lines 20-23	1,3,5-7, 11
X	US 4 015 657 A (PETROV DMITRY ANDREEVICH ET AL) 5 April 1977 (1977-04-05) column 3, lines 46-68; figure 1	1,2,7
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 July 2011	08/07/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lemoisson, Fabienne

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 041 236 A (CRYSTAL SYST) 10 September 1980 (1980-09-10) figures 1,2	1,12,13
A	US 6 200 385 B1 (SWINEHART CARL FRANCIS [US]) 13 March 2001 (2001-03-13)	12
X	WO 2007/148985 A1 (REC SCANWAFER AS [NO]; JULSRUD STEIN [NO]; NAAS TYKE LAURENCE [NO]) 27 December 2007 (2007-12-27) page 3, lines 6-13; figure 1 page 4, lines 10-17 abstract	14-17
X	WO 2007/148987 A1 (REC SCANWAFER AS [NO]; JULSRUD STEIN [NO]; NAAS TYKE LAURENCE [NO]) 27 December 2007 (2007-12-27) abstract page 3, lines 34-35 page 4, lines 1-6,29-32 page 5, lines 3-14,27-28	14-17
Y	US 2008/292524 A1 (RANCOULE GILBERT [FR]) 27 November 2008 (2008-11-27) paragraph [0025]; claims 11,12	14-17
A	US 4 764 195 A (ALLAIRE ROGER A [US] ET AL) 16 August 1988 (1988-08-16)	14-17
A,P	US 2010/083895 A1 (EINHAUS ROLAND [FR] ET AL) 8 April 2010 (2010-04-08)	14-17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2011/050392

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [X] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[X] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 2-11, 18-20(completely); 1(partially)

   a directional solidification furnace comprising a crucible including a base having an opening therein through all the thickness of the base with a particular geometry, a plate being received in this opening, the plate having a particular geometry (complementary to the geometry of the opening) with a thickness similar to that of the base and the plate having a higher thermal conductivity than the base

   ---

2. claims: 12, 13(completely); 1(partially)

   a directional solidification furnace comprising a crucible including a base having an opening therein not extending through all the thickness of the base with a particular geometry, a plate being received in this opening, the plate having a particular geometry (complementary to the geometry of the opening) with a thickness similar to that of the base and the plate having a higher thermal conductivity than the base

   ---

3. claims: 14-17

   a directional solidification furnace comprising a crucible including a base being a composite base, the composite base including an additive such that the composite base has a higher thermal conductivity than the base without additive

   ---

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2011/050392

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
GB 2084978	A	21-04-1982	BE	890508	A1	18-01-1982
			CA	1193522	A1	17-09-1985
			CH	653714	A5	15-01-1986
			DE	3138227	A1	22-07-1982
			FR	2491095	A1	02-04-1982
			IT	1144865	B	29-10-1986
			JP	57085667	A	28-05-1982
			NL	8104333	A	16-04-1982
DE 4236827	A1	05-05-1994	NONE			
US 4015657	A	05-04-1977	NONE			
GB 2041236	A	10-09-1980	BE	880839	A1	16-04-1980
			DE	3001815	A1	31-07-1980
			FR	2446873	A1	14-08-1980
			IT	1192791	B	04-05-1988
			JP	56009298	A	30-01-1981
			JP	55100294	A	31-07-1980
			NL	8000094	A	22-07-1980
US 6200385	B1	13-03-2001	US	6277351	B1	21-08-2001
WO 2007148985	A1	27-12-2007	CN	101495681	A	29-07-2009
			EP	2035604	A1	18-03-2009
			JP	2009541193	A	26-11-2009
			KR	20090024802	A	09-03-2009
			US	2009314198	A1	24-12-2009
WO 2007148987	A1	27-12-2007	CN	101479410	A	08-07-2009
			EP	2038454	A1	25-03-2009
			JP	2009541195	A	26-11-2009
			KR	20090023498	A	04-03-2009
			US	2009208400	A1	20-08-2009
US 2008292524	A1	27-11-2008	AT	480650	T	15-09-2010
			AU	2007204406	A1	19-07-2007
			BR	PI0706222	A2	22-03-2011
			CA	2634199	A1	19-07-2007
			CN	101370968	A	18-02-2009
			DK	1979512	T3	17-01-2011
			EP	1811064	A1	25-07-2007
			EP	1979512	A1	15-10-2008
			WO	2007080120	A1	19-07-2007
			ES	2349158	T3	28-12-2010
			JP	2009523115	A	18-06-2009
US 2008292524	A1		KR	20080082978	A	12-09-2008
			PT	1979512	E	09-11-2010
			SI	1979512	T1	30-11-2010
			ZA	200805509	A	30-12-2009
US 4764195	A	16-08-1988	EP	0291905	A2	23-11-1988
			JP	63307185	A	14-12-1988
US 2010083895	A1	08-04-2010	CN	101356305	A	28-01-2009
			EP	1969163	A1	17-09-2008
			FR	2895749	A1	06-07-2007

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2011/050392

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		WO 2007077305 A1	12-07-2007
		JP 2009522201 A	11-06-2009
		ZA 200805389 A	28-10-2009

Form PCT/ISA/210 (patent family annex) (April 2005)