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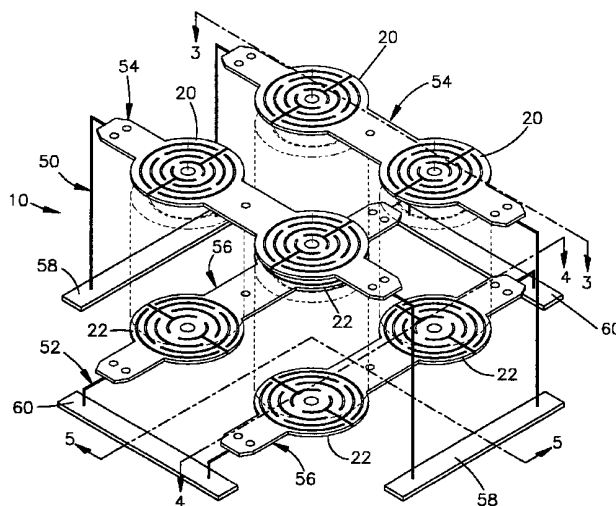
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(54) Title: HEATER ARRANGEMENT FOR CRYSTAL GROWTH FURNACE



(57) Abstract: A furnace (10) for growing crystals includes a plurality of growth stations (14) and first (50) and second (52) heater matrices. Each growth station (14) has a crucible (16) and an insulating container (18) generally surrounding the crucible (16) and thermally isolating the crucible (16) from the other growth stations (14). The first (50) and second (52) heater matrices each include at least two legs (54, 56) electrically connected, each of which have at least two heaters (20, 22) electrically connected in series. Each of the growth stations (14) have at least one of the heaters (20, 22) within the first heater matrix (50) and at least one of the heaters (20, 22) within the second heater matrix (52) associated therewith. The heaters (20, 22) of the first heater matrix (50) are located above the crucibles (16) and are adapted to provide a homogeneous temperature there. The heaters (20, 22) of the second heater matrix (52) are located below the crucible (16) and are adapted to provide a temperature gradient there.



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HEATER ARRANGEMENT FOR CRYSTAL GROWTH FURNACE

1 This a continuation-in-part of Application Number
2 09/349,597 filed on July 9, 1999, which claims priority
3 of provisional Patent Application No. 60/141,389 filed on
4 June 29, 1999.

5 BACKGROUND OF THE INVENTION

6 The present invention generally relates to a heater
7 arrangement for a furnace and, more specifically, to a
8 heater arrangement for a crystal growth furnace suitable
9 for producing a high volume of crystals.

10 Furnaces for the production of crystals, such as
11 single crystals of calcium fluoride, typically have a
12 crucible which is loaded with a seed and/or starting
13 material. A heater (or heaters) is arranged about the
14 crucible to produce a temperature gradient to grow the
15 crystals in the crucible. Growth is obtained by varying
16 power to the heater according to an established power-
17 temperature relationship to obtain the desired thermal
18 environment.

19 The thermal gradient obtained is critical to growing
20 a single crystal rather than a polycrystalline
21 structures. Additionally, the quality of a single
22 crystal is believed to be primarily affected by the
23 applied thermal gradient. Present furnaces for the

1 production of macrocrystals, therefore, have elaborate
2 and complex heaters and/or controllers for controlling
3 the heaters to obtain the desired thermal environment.
4 These complex devices are expensive to produce and
5 complicated to operate and maintain.

6 Further, high quality calcium fluoride crystals are
7 of great need in the semiconductor manufacturing
8 industry. Commercial success in growing large,
9 monocrystalline ingots from calcium fluoride, has been
10 limited to ingots have a diameter of 15 inches or less.

11 In high volume production of crystals it is
12 important to obtain the desired thermal environment and
13 is also important to get consistent temperature
14 environments. In addition, large diameter single-crystal
15 growth requires increased precision and consistency in
16 control of temperature environment. Accordingly, there
17 is a need in the art for a crystal growth furnace which
18 is simple to produce and operate, produces desired
19 thermal environments for growing crystals, and produces
20 consistent thermal environments for growing a high volume
21 of crystals and for growing crystals of a large diameter.

22 BRIEF SUMMARY OF THE INVENTION

23 The present invention provides a furnace for growing
24 crystals which overcomes at least some of the above-noted
25 problems of the prior art. According to the present
26 invention, a heater arrangement for a crystal growth
27 furnace includes a plurality of individual growth

1 stations each having a crucible. The crystal growth
2 furnace also includes a first heater matrix having at
3 least two resistance heaters electrically connected in
4 series or parallel. Each of the individual growth
5 stations has at least one of the resistance heaters of
6 the first heater matrix associated therewith and located
7 near the crucible. By connecting the resistance heaters
8 of separate growth stations in this manner, the
9 temperatures produced by the resistance heaters in the
10 separate growth stations are fixed at the same
11 temperature for a given power level when the resistance
12 heaters are connected to a single power source.

13 According to another aspect of the present
14 invention, a heater arrangement for growing crystals
15 includes a plurality of individual growth stations each
16 having a crucible. The heater arrangement also includes
17 a first heater matrix and a second heater matrix separate
18 from the first heater matrix. Each heater matrix
19 preferably includes at least two legs electrically
20 connected in parallel with each of the legs having at
21 least two resistance heaters electrically connected in
22 series. Each of the individual growth stations has at
23 least one of the resistance heaters of the first heater
24 matrix and at least one of the resistance heaters of the
25 second heater matrix associated therewith. By having two
26 separate heater matrices, the temperatures produced by
27 the resistance heaters in a large quantity of separate
28 growth stations can be fixed at the same temperature for

1 a given power level yet the temperature gradient formed
2 in each of the growth stations can be varied when each
3 heater matrix is connected to a separate power source.
4 Preferably, the resistance heaters within the first
5 heater matrix are located above the crucibles and provide
6 a homogeneous temperature across the top of the crucibles
7 and the resistance heaters within the second heater
8 matrix are located below the crucibles and provide a
9 temperature gradient across the bottom of the crucibles.

10 BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

11 These and further features of the present invention
12 will be apparent with reference to the following
13 description and drawings, wherein:

14 FIG. 1 is a perspective view of a crystal growth
15 furnace having a plurality of individual growth stations
16 for producing a high volume of macrocrystals according to
17 the present invention and with components, such as a
18 vacuum chamber, removed for clarity;

19 FIG. 2 is a perspective view of the crystal growth
20 furnace of FIG. 1 with further components, such as
21 crucibles, removed for clarity to show a heater matrix;

22 FIG. 3 is a plan view of an upper resistance heater
23 of the arrangement of FIG. 2;

24 FIG. 4 is a plan view of an lower resistance heater
25 of the arrangement of FIG. 2;

1 FIG. 5 is an enlarged elevational view, in cross-
2 section, of one crucible of the crystal growth furnace of
3 FIG. 1;

4 FIG. 6 is a perspective view of a crystal growth
5 furnace having a plurality of individual growth stations
6 for producing a high volume of macrocrystals according to
7 a second embodiment of the present invention with
8 components, such as a vacuum chamber, removed for
9 clarity;

10 FIG. 7 is a perspective view of a crystal growth
11 furnace having a plurality of individual growth stations
12 for producing a high volume of macrocrystals according to
13 a third embodiment of the present invention with
14 components, such as a vacuum chamber and crucibles,
15 removed for clarity to show a heater matrix;

16 FIG. 8 is a perspective view of a crystal growth
17 furnace having a plurality of individual growth stations
18 for producing a high volume of macrocrystals according to
19 a fourth embodiment of the present invention with
20 components, such as a vacuum chamber and crucibles,
21 removed for clarity to show a heater arrangement; and

22 FIG. 9 is a plan view similar to FIGS. 3 and 4 but
23 showing an alternative heater leg.

24 FIG. 10 is an enlarged elevational view, in cross
25 section, similar to FIG. 5 but showing an alternative
26 bottom heater.

27 FIG. 11 is a detail of the bottom heater shown in
28 FIG. 10.

1 FIG. 12 is an plan view showing an alterative bottom
2 heater.

3 FIG. 13 is a detail of a portion of the bottom
4 heater of FIG. 12.

5 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

6 FIG. 1 illustrates a heat treatment or vacuum
7 furnace 10 according to the present invention suitable
8 for growing a high volume of crystals. The crystal
9 growth furnace 10 can be used to grow low and high
10 temperature crystals using, for example, melt, Vapor
11 Phase Epitaxy (including VPE, MVPE and OMVPE), Chemical
12 Vapor Deposition (CVD) and thin film processes. The
13 crystal furnace 10 can be used to grow crystals of a
14 variety of different materials such as calcium fluoride,
15 sodium iodide, and cesium iodide etc. The crystal growth
16 furnace 10 is particularly useful in growing single
17 macrocrystals having diameters of, for example, up to
18 about four feet and larger but can also be used to grow
19 other types of crystals such as microcrystals or
20 polycrystalline structures.

21 As best shown in FIGS. 1 and 5, the crystal growth
22 furnace 10 includes a water-cooled pressure vessel or
23 vacuum chamber 12 and a plurality of individual growth
24 stations 14 located within the vacuum chamber 12. The
25 vacuum chamber 12 preferably operates at a pressure of 10
26 millitorr or less. The dimensions of the vacuum chamber
27 12 depend on the size and number of individual growth

1 stations 14 located therein. In the illustrated
2 embodiment there are four individual growth stations but
3 a greater or lesser number can be utilized as discussed
4 in more detail hereinbelow.

5 Each individual growth station 14 includes a
6 crucible 16 in which a crystal will grow, an insulating
7 container or cylinder 18 surrounding the crucible 16, and
8 two heaters 20, 22 located within the insulating cylinder
9 18 and adjacent the crucible 16. Preferably, a top
10 heater 20 is located above the crucible 16 and a bottom
11 heater 22 is located below the crucible 16. It is noted,
12 however, that other heater locations such as around the
13 sides of the crucible 18 are within the scope of the
14 present invention.

15 The illustrated crucible 16 is cylindrical or cup-
16 shaped having a side wall 24 and a bottom wall 26. The
17 crucible 16 is formed of a suitable material such as, for
18 example, graphite, carbon, or other carbon composites.
19 The dimensions of the crucible 16 depend on the desired
20 size of the crystal to be grown therein. A crucible
21 believed suitable for growing single crystals of calcium
22 fluoride has an outer diameter of about 5.5 inches, an
23 outer height of about 12 inches, an inner diameter of
24 about 4 inches, and an inner height of about 10.75
25 inches. Suitable ranges for the crucible dimensions are
26 believed to be an outer diameter of from about 2 inches
27 to about 40 inches, an outer height of from about 6
28 inches to about 40 inches, an inner diameter of from

1 about 1 inch to about 38 inches, and an inner height of
2 from about 3 inches to about 36 inches.

3 The top opening of the crucible 16 is closed by a
4 lid or cover 27. The lid 27 is formed of a suitable
5 material such as graphite or carbon composite.

6 The perimeter of the crucible 16 is provided with
7 suitable insulation 28. The insulation 28 comprises a
8 suitable material such as rigidized carbon felt or
9 rigidized carbon foam. The inner surface of the
10 insulation 28 preferably has a thin layer of graphite
11 foil or GRAFOIL for increased reflection of the
12 radiation. This thin layer of graphite foil preferably
13 has a thickness in the range of about 1/32 inch to about
14 1/8 inch. The insulation 28 preferably extends the
15 entire height of the crucible 16 from the top to the
16 bottom of the side wall 24. The insulation 28 preferably
17 extends about 1 to 6 inches from the outer diameter of
18 the crucible side wall 24 but not beyond the outer
19 diameter of the top and bottom heaters 20, 22.

20 Insulation having a thickness of about 1.5 inches is
21 believed suitable for the above described crucible for
22 growing single crystals of calcium fluoride but it may be
23 thicker or thinner depending on the insulation heat
24 transfer characteristics. It is noted that the
25 insulation 28 is located at other locations about the
26 crucible 16 when the heaters 20, 22 heaters have other
27 locations.

1 The crucible 16 is supported by a pedestal 30
2 downwardly extending from the bottom wall 26, through the
3 bottom heater 22, and rests in a cup or adapter. The cup
4 rests on a shaft 32 which extends through the base plate
5 or bottom wall 34 of the vacuum chamber 12. The pedestal
6 30 is formed of a suitable material such as, for example,
7 graphite or carbon composite while the cup is formed of a
8 suitable material such as steel or inconel, and the shaft
9 32 is formed of a suitable material such, for example, as
10 stainless steel or inconel. The pedestal 30 extends into
11 or otherwise supports the bottom wall 26 of the crucible
12 16 and is preferably provided with an upward facing
13 recess or pocket 35 for holding a seed or starting
14 material. A pocket having a diameter of about 7/16
15 inches, a length of about 1.5 inches and extending into
16 the crucible about 1 inch is believed suitable for the
17 above described crucible to receive starting material for
18 growing single crystals of calcium fluoride. The seed
19 pocket diameters described above are for crystals having
20 diameters up to about 13 inches, crystals having larger
21 diameters should have seeds greater than about 1 inch in
22 diameter.

23 The insulating cylinder 18 is adapted to generally
24 surround the crucible 16 and the top and bottom heaters
25 20, 22 so that the top and bottom heaters 20, 22 are
26 insulated from the top and bottom heaters 20, 22 of the
27 other individual growth stations 14 so that each of the
28 individual growth stations 14 will be thermally

1 independent of the others. The illustrated insulating
2 cylinder 18 has a cylindrically-shaped side wall 36, a
3 top wall 38 generally closing the open upper end of the
4 side wall 36, and a bottom wall 40 generally closing the
5 lower open end of the side wall 36. The side, top, and
6 bottom walls 36, 38, 40 comprise suitable insulation
7 material such as rigidized carbon felt or rigidized
8 carbon foam. The insulation material is preferably
9 suitable for maintaining a temperature difference of
10 about 1000° C to about 1300° C. The side wall 36 is
11 sized so that the top and bottom heaters 20, 22 can
12 reside within the inner diameter of the side wall 36 and
13 is provided with suitable openings 42, 44 for the passage
14 of the top and bottom heaters 20, 22 therethrough. The
15 surface of the inner diameter of the insulating cylinder
16 18 preferably has a thin layer of graphite foil or
17 GRAFOIL for increased reflection of the radiation and
18 reduced radiation losses. This layer of graphite foil is
19 also preferably located on the inner surfaces of the top
20 and bottom walls 38, 40. This layer preferably has a
21 thickness in the range of about 1/32 inch to about 1/8
22 inch. An insulating cylinder having wall thicknesses of
23 about 2 inches, an inner diameter of about 9 inches, and
24 an interior height of about 16 inches is believed
25 suitable for the above described crucible for growing
26 single crystals of calcium fluoride. Suitable ranges for
27 the insulating cylinder dimensions are believed to be
28 wall thicknesses of from about 2 inches to about 4

1 inches, an inner diameter of from about 4 inches to about
2 72 inches, and an interior height of from about 6 inches
3 to about 48 inches.

4 The bottom wall 40 of the insulating cylinder 18 is
5 provided with a suitable opening 46 for passage of the
6 pedestal 30 therethrough. Preferably, a base 48 is
7 provided which supports the side, top and bottom walls
8 36, 38, 40 and positions the walls 36, 38, 40 about the
9 crucible 16 and the top and bottom heaters 20, 22.

10 As best shown in FIG. 2, the top heaters 20 of the
11 individual growth stations 14 are suitably connected to
12 form a top or first heater matrix 50 and the bottom
13 heaters 22 of the individual growth stations 14 are
14 suitably connected to form a bottom or second heater
15 matrix 52. Each heater matrix 50, 52 includes at least
16 one leg 54, 56 of two or more of the heaters 20, 22
17 connected in series or at least two heater legs 54, 56
18 which are connected in parallel. Preferably, each heater
19 matrix 50, 52 includes at least two heater legs 54, 56
20 with each heater leg 54, 56 having at least two heaters
21 20, 22. The illustrated heater matrices 50, 52 each have
22 two heater legs 54, 56 of two heaters 20, 22 to
23 accommodate the four individual growth stations 14. As
24 noted hereinabove, the number of heater legs 54, 56 and
25 the number of heaters 20, 22 in each heater leg 54, 56
26 can be greater or lesser depending on the number of
27 individual growth stations 14 desired. Moreover, each
28 heater matrix 50, 52 may be two or more heaters 20, 22

1 only connected in series, only connected in parallel, or
2 a combination of both.

3 Power is distributed to the heater matrices 50, 52
4 by way of bus bars 58, 60. Preferably, the bus bars 58,
5 60 are all located at the same height near the bottom of
6 the individual growth stations 14. The bus bars 58, 60
7 are formed of a suitable material such as, for example,
8 graphite or carbon composite. Each heater matrix 50, 52
9 has a separate pair of the bus bars 58, 60 wherein all of
10 the heater legs 54, 56 of the heater matrix 50, 52 are
11 suitably connected in parallel between the pair of bus
12 bars 58, 60.

13 As best shown in FIG. 5, the heater legs 54, 56 are
14 connected to the bus bars 58, 60 and the bus bars 58, 60
15 are connected to copper feed-through electrodes 62, 64
16 which extend through the bottom wall 34 of the vacuum
17 chamber 12. The bus bars 58, 60 are preferably connected
18 to the copper feed-through electrodes 62, 64 via graphite
19 electrodes 63, 65. Graphite bus bars having a height of
20 about 1 inch, a width of about 4 inches, and a length of
21 about 16 inches are believed to be suitable for a four
22 station furnace having a heater matrix with two legs of
23 two heaters each and the above described crucibles for
24 growing single crystals of calcium fluoride. Suitable
25 ranges for the bus bars are believed to be a height of
26 from about 1 inch to about 5 inches, a width of from
27 about 1 inch to about 5 inches, and a length of from
28 about 6 inches to about 500 inches.

1 The heater legs 54, 56 are positioned above and
2 below the crucibles 16 and pass through the insulating
3 cylinders 18 via the openings 42, 44. The top heater leg
4 54 is positioned between and spaced apart from the lid 27
5 of the crucible 16 and the top wall 38 of the insulating
6 cylinder 18. The bottom heater leg 56 is positioned
7 between and spaced apart from the bottom wall 26 of the
8 crucible 16 and the bottom wall 40 of the insulating
9 cylinder 18. Spacings of about 0.75 inches from the lid
10 27 of the crucible 16, about 0.5 inches from the top wall
11 38 of the insulating cylinder 18, about 1.25 inches from
12 the bottom wall 26 of the crucible 16, and about .75
13 inches from the bottom wall 40 of the insulating cylinder
14 18 are suitable with the above described crucibles for
15 growing single crystals of calcium fluoride. Suitable
16 ranges for the spacings are believed to be from about
17 0.25 inches to about 1 inch for the distance from the lid
18 27 of the crucible 16, from about 0.5 inches to about 3
19 inches for the distance from the top wall 38 of the
20 insulating cylinder 18, from about 0.25 inches to about 1
21 inch for the distance from the bottom wall 26 of the
22 crucible 16, and from about 0.5 inches to about 3 inches
23 from the bottom wall 40 of the insulating cylinder 18.

24 In the illustrated embodiment, vertically extending
25 supports or posts 66, 67 are provided between the heater
26 legs 54, 56 and the bus bars 58, 60 at the ends of the
27 heater legs 54, 56. The posts 66, 67 both support the
28 heater legs 54, 56 and electrically connect the heater

1 legs 54 to the bus bars 58, 60. It is noted that the
2 heater legs 54, 56 are preferably self supporting between
3 the posts 66, 67 at the ends of the heater legs 54, 56
4 but, if necessary, intermediate posts can be utilized.
5 The posts 66, 67 are formed of a suitable material such
6 as, for example, graphite or carbon composite.

7 The posts 66, 67 are sized to position the heater
8 legs 54, 56 above and below the crucible 16 respectively
9 at their desired heights. A top heater post 66 having a
10 upper portion diameter of about 2 inches, an upper
11 portion length of about 1.5 inches, a lower portion
12 diameter of about 1.5 inches, and a lower portion length
13 of about 15.5 inches is believed to be suitable for a
14 four station furnace having a heater matrix with two legs
15 of two heaters each and the above described crucibles for
16 growing single crystals of calcium fluoride. Suitable
17 ranges for the dimensions of the top heater post 66 are
18 believed to be an upper portion diameter of from about 2
19 inches to about 6 inches, an upper portion length of from
20 about 1 inch to about 3 inches, a lower portion diameter
21 of from about 1 inch to about 3 inches, and a lower
22 portion length of from about 6 inches to about 20 inches.
23 A bottom heater post 67 having a upper portion diameter
24 of about 2 inches, an upper portion length of about 1.5
25 inches, a lower portion diameter of about 1.5 inches, and
26 a lower portion length of about 1.25 inches is believed
27 to be suitable for a four station furnace having a heater
28 matrix with two legs of two heaters each and the above

1 described crucibles for growing single crystals of
2 calcium fluoride. Suitable ranges for the dimensions of
3 the bottom heater post 67 are believed to be an upper
4 portion diameter of from about 2 inches to about 6
5 inches, an upper portion length of from about 1 inch to
6 about 3 inches, a lower portion diameter of from about 1
7 inch to about 3 inches, and a lower portion length of
8 from about 3 inches to about 12 inches.

9 As best shown in FIGS. 3 and 4, the heaters 20, 22
10 and heater legs 54, 56 are electric resistance heaters
11 and are preferably formed from a single sheet or bar of
12 material. The heater legs 54, 56 preferably comprise
13 graphite or other suitable materials such as, for
14 example, a carbon-carbon composite, a polycarbon
15 composite, or silicon carbide.

16 In the illustrated embodiment each heater leg 54, 56
17 has two of the heaters 20, 22 formed therein. Each
18 heater leg preferably has a central portion 68, 70
19 connecting the heaters 20, 22 and end portions 72, 74
20 extending from opposite sides of the heaters 20, 22. The
21 end portions 72, 74 are adapted to be connected to the
22 bus bars 58, 60 such as, for example, providing openings
23 for the passage of fasteners therethrough. It is noted
24 that additional or fewer heaters 20, 22 can be formed in
25 a single heater leg 54, 56 as discussed in more detail
26 hereinafter. Graphite heater legs 54, 56 having a
27 thickness of about 5 mm, a total length of about 29.5
28 inches, heater outer diameters of about 8.25 inches, a

1 central portion length of about 4 6/8 inches, end portion
2 lengths of about 4 1/8 inches, and central and end
3 portion widths of about 3 to about 5 inches are believed
4 to be suitable for a four station furnace having a heater
5 matrix with two legs of two heaters each and the above
6 described crucibles for growing single crystals of
7 calcium fluoride. Suitable ranges for the dimensions of
8 the heater legs 54, 56 are believed to be a thickness of
9 from about 2 mm to about 18 mm, a total length of from
10 about 8 inches to about 108 inches, heater outer
11 diameters of from about 6 inches to about 40 inches, a
12 central portion length of from about 4 inches to about 10
13 inches, end portion lengths of from about 4 inches to
14 about 8 inches, and central and end portion widths of
15 from about 2 inches to about 6 inches.

16 Each heater 20, 22 preferably has body with a
17 generally circular outer periphery and a constant
18 thickness. The body is provided with gaps or slots 76,
19 78 which produce a "zig-zag" circuit of current flow
20 paths. The flow paths are preferably formed by arcuate
21 or curved circumferentially extending sections 80, 82
22 connected at their ends. In the illustrated embodiment,
23 there are five sections 80, 82 but a greater or lesser
24 number of sections 80, 82 can be utilized. A first half
25 of the body has two separate current flow paths which
26 extend from the first or outermost section 80a, 82a to
27 the fifth or innermost section 80e, 82e and a second half
28 of the body two separate current flow paths which extend

1 from the innermost section 80a, 82a to the outermost
2 section 80e, 82e. Note that the first and second halves
3 of the body are isolated from one another except at the
4 fifth or inner most section 80a, 82a. Preferably, the
5 two current flow paths are connected along their lengths
6 at intermediate points between the innermost section 80a,
7 82a to the outermost section 80e, 82e. The current flow
8 paths of illustrated embodiment are connected at the
9 junction between the second sections 80b, 82b and the
10 third sections 80c, 82c and at the junction between the
11 fourth sections 80d, 82d and the fifth sections 80e, 82e.

12 The heaters 20, 22 within each heater matrix 50, 52
13 can be the same or different depending on the needs of
14 the crystal growth furnace 10. Each of the heaters 20,
15 22 within a heater matrix 50, 52 can be the same, that
16 is, have the same resistance such that for any given
17 amperage/voltage, the temperature will be the same at the
18 individual growth stations 14. The heaters 20, 22 within
19 a heater matrix 50, 52 can alternatively each have a
20 different resistance such that for any given
21 amperage/voltage, the temperature will be higher or lower
22 at the various individual growth stations 14. In the
23 illustrated embodiment, each of the top heaters 20 within
24 the top heater matrix 50 are the same and each of the
25 bottom heaters 22 within the bottom heater matrix 52 are
26 the same.

27 Likewise, the top and bottom heaters 20, 22 of each
28 individual growth station 14 can be the same or different

1 depending on the needs of the growth stations 14. In the
2 illustrated embodiment, the top and bottom heaters 20
3 within each growth station 14 are different.

4 As best shown in FIG. 3, each top heater 20 is
5 designed to provide, at any given amperage/voltage, a
6 homogeneous thermal environment across the top of the
7 crucible 16. Accordingly, the sections 80a-80e each have
8 substantially the same width. The dimensions of the top
9 heater 20 depend on the thermal environment desired and
10 the amperage/voltage desired to be supplied. A graphite
11 top heater having a thickness of about 5 mm, an outer
12 diameter of about 8.25 inches, an inner diameter of about
13 1 inch, gap widths of about 1/8 inch, and section widths
14 of about 5/8 inch is believed to be suitable for the
15 above described crucibles for growing single crystals of
16 calcium fluoride. Such top heaters preferably operate
17 with total power of about 20 kw (for two legs of two
18 heaters) and have a total resistance of about .0508 ohms
19 (for two legs of two heaters), therefore there is about
20 627 amps and 32 volts secondary (going to the bus) and
21 about 85 amps and 240 volts primary (going to the
22 transformer (step down factor of 2.5)). Other
23 dimensions, resistances, and power will be obvious to one
24 skilled in the art to obtain desired thermal
25 environments.

26 As best shown in FIG. 4, each bottom heater 22 is
27 designed to provide, at any given amperage/voltage, a
28 radial thermal gradient across the bottom of the

1 crucible, that is, a thermal environment with an
2 increasing temperature in the radial direction, from the
3 center of the crucible 16 to the outer periphery of the
4 crucible 16. The innermost section 82e of the heater 22
5 is the coldest section and the temperature of each of the
6 sections 82a-82e gradually increases to the outermost
7 section 82a which is the hottest section. This
8 temperature gradient ensures that the origin of the
9 crystal growth will be at one position within the
10 crucible 16 and that location is at the central axis of
11 the crucible 16.

12 The dimensions of the bottom heater 22 depend on the
13 thermal environment desired and the amperage/voltage
14 desired to be supplied. For a given bottom heater, the
15 width of the outermost current path should be about 1/2
16 of the width of the innermost current path. A graphite
17 bottom heater having a thickness of about 5 mm, an outer
18 diameter of about 8.25 inches, an inner diameter of about
19 1 inch, gap widths of about 1/8 inch, and increasing
20 section widths of about 3/8 inch, about 4/8 inch, about
21 5/8 inch, about 6/8 inch, and about 7/8 inch is believed
22 to be suitable for the above described crucibles for
23 growing single crystals of calcium fluoride. Such bottom
24 heaters preferably operate with total power of about 20
25 kw (for two legs of two heaters) and have a total
26 resistance of about .06895 ohms (for two legs of two
27 heaters), therefore there is about 540 amps and 37 volts
28 secondary (going to the bus) and about 83 amps and 240

1 volts primary (going to the transformer (step down factor
2 of 2.5)).

3 To produce a uniform thermal gradient across the
4 surface of the bottom heater 22, the width of the current
5 flow path 82 at each bend 83 must be carefully selected,
6 depending upon the widths of the two segments of the path
7 82 that the bend 83 connects. An appropriate value for a
8 bend width, T , has been determined experimentally to be
9 calculated by,

10
$$T = \frac{A+B}{1.79} \cdot \frac{1}{2} ;$$

11 where A and B are the widths of the connected paths.

12 Where two bends are involved the calculation becomes,

13
$$T = \frac{A+B}{1.79} .$$

14 Other dimensions, resistances, and power will be obvious
15 to one skilled in the art to obtain desired thermal
16 environments.

17 The heaters 20, 22 are constructed of a high
18 strength poly carbon material having a suitable
19 resistance and a tensile strength sufficient to withstand
20 the thermal expansion to support its own weight. One
21 such suitable material is available under the trade name
22 of SIGRIBOND.

1 As best shown in FIG. 1, the heaters 20, 22 of each
2 heater matrix 50, 52 are connected to a single power
3 source 84, 86 so that at any given power level, the
4 temperature of all the heaters 20, 22 within the heater
5 matrix 50, 52 are fixed and may or may not be the same
6 through out the heater matrix 50, 52 depending on the
7 individual design of the heaters 20, 22. Preferably, the
8 heater matrices 50, 52 each have a separate power source
9 84, 86. A first power source 84 controls the upper
10 heater matrix 50 and a second power source 86 controls
11 the lower heater matrix 52 so that the temperature of the
12 heater matrices 50, 52 relative to each other can be
13 varied. The separate power sources 84, 86 of the heater
14 matrices 50, 52 are preferably controlled by a single
15 controller 88. The power sources 84, 86 and the
16 controller 88 can be conventional.

17 FIG. 6 illustrates a heat treatment or vacuum
18 furnace 100 according to a second embodiment of the
19 present invention wherein like reference numbers are used
20 for like structure. The crystal growth furnace 100
21 illustrates that additional levels or layers of
22 individual growth stations 14 can be utilized. In the
23 illustrated embodiment there are three levels of four
24 individual growth stations 14 so that the crystal growth
25 furnace 100 has twelve individual growth stations 14.
26 Each heater matrix 50, 52 includes six heater legs 54, 56
27 connected in parallel with each leg having two heater 20,
28 22 to accommodate the twelve individual growth stations

1 14. While the illustrated embodiment has three levels,
2 it is noted that a greater or lesser number of layers can
3 be utilized. It is also noted that the features of the
4 second embodiment can be utilized alone or in combination
5 with each of the features of each of the other disclosed
6 embodiments.

7 FIG. 7 illustrates a heat treatment or vacuum
8 furnace 200 according to a third embodiment of the
9 present invention wherein like reference numbers are used
10 for like structure. The crystal growth furnace 200
11 illustrates that the top heater legs 54 can extend
12 parallel to the bottom heater legs 56 rather than
13 perpendicular as in the first embodiment. Accordingly,
14 the bus bars 58, 60 are parallel on one side rather than
15 perpendicular on different sides as in the first
16 embodiment. In this embodiment the top heater legs 54
17 have a larger length than the bottom heater legs 56. It
18 is also noted that the features of the third embodiment
19 can be utilized alone or in combination with each of the
20 features of each of the other disclosed embodiments.

21 FIG. 8 illustrates a heat treatment or vacuum
22 furnace 300 according to a fourth embodiment of the
23 present invention wherein like reference numbers are used
24 for like structure. The crystal growth furnace 300
25 illustrates that there can be additional heater legs 54,
26 56 and that the heater legs 54, 56 can have addition
27 heaters 20, 22. In the illustrated embodiment, there are
28 three heater legs 54, 56 each having three heaters 20, 22

1 so that the crystal growth furnace 300 has one level of
2 nine individual growth stations 14. While the
3 illustrated embodiment has one level, three heater legs
4 54, 56, and three heaters 20, 22 in each heater leg 54,
5 56, it is noted that a greater number of layers can be
6 utilized a greater or lesser number of heater legs 54, 56
7 in each layer can be utilized, and a greater of lesser
8 number of heaters 20, 22 in each heater leg 54, 56 can be
9 utilized. It is also noted that the features of the
10 fourth embodiment can be utilized alone or in combination
11 with each of the features of each of the other disclosed
12 embodiments.

13 It is noted that the fourth embodiment can be
14 particularly advantageous wherein the heaters 20, 22 are
15 different within the heater matrices 50, 52 to form
16 different thermal environments on different individual
17 growth stations 14. This allows the furnace to be
18 utilized to grow crystals using a continuous process
19 technique. In the continuous process technique, material
20 is loaded into containers at one end of the crystal
21 growth furnace 300 and the material passes through a
22 number of individual growth stations 14 having different
23 thermal gradients. For example, the material can pass
24 through individual growth stations 14 which are adapted
25 to separately heat up starting material, grow the
26 crystal, and cool down the crystal to room temperature.

27 FIG. 9 illustrates an alternative heater leg 90
28 wherein like reference numbers are used for like

1 structure. The heater leg 90 illustrates that the heater
2 legs can have shapes other than the above described
3 linear configuration (FIGS. 3 and 4), such as the
4 illustrated circular configuration. In the illustrated
5 embodiment, the heater leg 90 is generally circular and
6 has six of the heaters 20, 22 incorporated therein. It
7 is noted that a greater or lesser quantity of the heaters
8 20, 22 can be utilized and the heaters 20, 22 can have
9 different locations than illustrated. It is also noted
10 that the alternative heater legs 90 can be utilized alone
11 or in combination with each of the disclosed embodiments.
12 The circular arrangement of the heater leg 90 can be
13 particularly advantageous when a plurality of circular
14 heater legs 90 of various diameters are coaxially
15 arranged.

16 FIGS. 10 and 11 show a sixth embodiment of the
17 bottom heater in which the heater 122 has a variable
18 thickness. In the embodiment of heater 22, an increase
19 in heat output from the center of the heater 22 outward
20 is produced by incrementally decreasing the width of the
21 current path, and thus increasing the electrical
22 resistance. In heater 122, as an alternate method of
23 increasing the resistance of the current path, the
24 thickness of the heater is gradually reduced from the
25 center of the heater outward. The particular thickness
26 used will depend on the characteristics of the thermal
27 gradient desired. This method can be used in place of
28 the variable-width flow path, or the two methods can be

1 used together to allow the heater designer more
2 flexibility in establishing a thermal gradient. It
3 should be noted that, while the method of heater 122
4 appears to by itself allow for a more evenly sloping
5 resistance, it has a practical limitation. In varying
6 the thickness of the heater 122, the center path becomes
7 the thickest part. If it becomes too heavy, it may flex
8 the heater and potentially cause a fracture or break.

9 FIG. 12 shows, as a seventh embodiment, an alternate
10 heater design 222 for growing significantly larger
11 crystals. Like bottom heater 22 shown in FIG. 4, this
12 heater 222 is designed to provide a thermal gradient
13 across the radius of the heater 222. Although the
14 thermal gradient produced by the bottom heater 22 is
15 sufficient to inhibit multiple point initiation of
16 crystal growth in crystals 15 inches or less in diameter,
17 growing larger single-crystal ingots requires a more
18 precise thermal gradient. Inherent to the design of the
19 heaters 20, 22, & 222 is the production of cold spots in
20 regions where the current flow path greatly increases in
21 size, especially at bends 83 in the current flow path.
22 As one of ordinary skill in the art will appreciate,
23 current always takes the path of least resistance. Thus,
24 as the current flow path 82a-82e of the heater 22
25 broadens at the bends 83 (see Fig. 4), the current tends
26 to flow more readily at the inside of the bends 83
27 producing cold spots toward the outside of the bends 83.
28 If these cold spots are transferred to the crucible 16,

1 undesirable crystal growth may be initiated at the point
2 of transfer.

3 As shown by FIG. 12, current flow paths 282, being
4 defined by slots 278, are divided into segments 282a,
5 282b, 282c, 282d and 282e that are connected by bends
6 283a, 283b, 283c and 283d. To mitigate the problem of
7 cold spots around the bends 283a-283d, the heater 222 has
8 been provided with slot extensions 278a at each bend
9 283b, 283c and 283d. The slot extensions 278a force the
10 current to flow toward the outside of the slot extensions
11 at the bends 283b-283d, thus reducing the presence of
12 cold spots on the heater 222. As an alternative, two or
13 more slot extensions could be provided to a single bend.

14 Referring to FIG. 13, in this seventh embodiment
15 each slot extension 278a is positioned at an angle θ from
16 a line perpendicular to the bisecting slot 279, the angle
17 θ being about 45 degrees for the optimal effect in
18 reducing cold spots. Although the slot extensions 278a
19 may not completely eliminate cold spots from appearing on
20 the bottom heater 222, due to the superior heat
21 conductivity of the crucible 16, any remaining cold spots
22 are "washed out", or greatly reduced, during the heat
23 transfer from the bottom heater 222 to the crucible 16.
24 As a result, any remaining cold spots on the bottom
25 heater 222 will not substantially appear on the bottom of
26 the crucible 16.

27 The extensions 278a are dimensioned to maintain the
28 width, T , of the bends 283a as calculated above.

1 Further, the slot extensions 278a are not used on the
2 outermost bend 283a in the present heater design because
3 it would weaken the current path 282 too much and may
4 cause the heater 222 to break when handled. However, if
5 a particular heater design were to possess adequate
6 strength, then slot extensions could be used at all of
7 the bends.

8 In addition to bottom heater design, selecting
9 heaters having an appropriate diameter is also crucial to
10 large single-crystal growth in the 20 to 30 inch range.
11 A specific example is illustrated as follows for growing
12 a single calcium fluoride crystal with a diameter of 28
13 inches. To allow for shrinkage due to cooling, the
14 inside diameter of the crucible should be determined by a
15 factor of approximately 1.035. Thus, a crucible with an
16 inside diameter of 29 inches is selected for this
17 example. The wall thickness of the crucible should be
18 determined from the inside diameter by a factor of 0.035.
19 In this example, the wall thickness will be 1 inch.
20 Thus, the outside diameter of the crucible will be 31
21 inches.

22 In order to insure the side wall of the crucible
23 gets hot enough to suppress crystal growth initiation,
24 the heaters should have a diameter that is no less than
25 1.2 times as great as the outside diameter of the
26 crucible, the preferred ratio being 1.3. Continuing the
27 above example, the diameter of the heaters used for a
28 crucible with an outside diameter of 31 inches should be

1 40 inches. The top heater will have the same diameter as
2 the bottom heater 28.

3 To establish a uniform horizontal gradient across
4 the bottom heater, and thus across the bottom of the
5 crucible, the number of current paths and the width of
6 each must be carefully selected. The ΔT across the
7 bottom heater should be between 12 and 15°C/inch from the
8 center to the outside edge. This should result in a ΔT
9 of between 5.5 and 7.5°C/inch across the bottom of the
10 inside of the crucible. This range should insure large
11 single-crystal sections across the grown ingot while
12 minimizing the strain birefringence and homogeneity index
13 of the ingot. If the ΔT is below this range, the single-
14 crystal sections will diminish in size, and if the ΔT is
15 above this range, the strain birefringence and
16 homogeneity will be too high.

17 The number of circumferential current paths required
18 on the bottom heater is dependent upon the diameter of
19 the heater and the material used to construct the heater.
20 The following chart has been compiled for determining the
21 number of current paths for a heater constructed of
22 SIGRIBOND carbon and producing a thermal gradient having
23 a ΔT of approximately 12.5°C/inch.

24	<u>Diameter (inches)</u>	<u>Current Paths</u>
25	15 - 27	3
26	28 - 40	5
27	41 - 53	7
28	54 - 66	9

1 The times and temperatures associated with the
2 annealing and cooling cycles used to grow a particular
3 crystal will depend upon the materials used, the overall
4 size and the quality of the crystal to be grown.
5 Although particular embodiments of the invention have
6 been described in detail, it will be understood that the
7 invention is not limited correspondingly in scope, but
8 includes all changes and modifications coming within the
9 spirit and terms of the claims appended hereto.

WHAT IS CLAIMED IS:

1 1. A heater arrangement for a crystal growth
2 furnace comprising:
3 a plurality of individual growth stations each
4 having a crucible;
5 a first heater matrix including at least two
6 resistance heaters electrically connected in series or
7 parallel, each of the individual growth stations having
8 at least one of said resistance heaters associated
9 therewith and located near said crucible; and
10 a power source connected to the first heater matrix.

1 2. The heater arrangement according to claim 1,
2 wherein said resistance heaters are located below said
3 crucibles.

1 3. The heater arrangement according to claim 2,
2 wherein said resistance heaters are adapted to provide a
3 thermal gradient across bottoms of said crucibles.

1 4. The heater arrangement according to claim 3,
2 wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired
5 thermal environments, said flow paths having cross-
6 sections of varying area to obtain said thermal gradient.

1 5. The heater arrangement according to claim 1,
2 wherein said resistance heaters are located above said
3 crucibles.

1 6. The heater arrangement according to claim 5,
2 wherein said resistance heaters are adapted to provide a
3 homogeneous thermal environment across tops of said
4 crucibles.

1 7. The heater arrangement according to claim 6,
2 wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired
5 thermal environments, said flow paths having cross-
6 sections of generally constant area to obtain said
7 homogeneous thermal environment.

1 8. The heater arrangement according to claim 1,
2 wherein said first heater matrix includes at least two
3 legs of at least two of said resistance heaters
4 electrically connected in series and said legs are
5 electrically connected in parallel.

1 9. The heater arrangement according to claim 1,
2 wherein said resistance heaters are adapted to provide
3 similar thermal environments for said individual growth
4 stations.

1 10. The heater arrangement according to claim 1,
2 wherein said resistance heaters are adapted to provide
3 different thermal environments for said individual growth
4 stations.

1 11. The heater arrangement according to claim 1,
2 further comprising a second heater matrix including at
3 least two resistance heaters electrically connected in
4 series or parallel, wherein said second heater matrix is
5 separate from said first heater matrix and each of said
6 individual growth stations has at least one of said
7 resistance heaters of said second heater matrix
8 associated therewith and located near said crucible.

1 12. The heater arrangement according to claim 11,
2 wherein said resistance heaters of said second heater
3 matrix are located below said crucibles.

1 13. The heater arrangement according to claim 12,
2 wherein said resistance heaters of said second heater
3 matrix are adapted to provide a thermal gradient across
4 bottoms of said crucibles.

1 14. The heater arrangement according to claim 12,
2 wherein said resistance heaters of said first heater
3 matrix are located above said crucibles.

1 15. The heater arrangement according to claim 14,
2 wherein said resistance heaters of said second heater
3 matrix are adapted to provide a thermal gradient across
4 bottoms of said crucibles.

1 16. The heater arrangement according to claim 15,
2 wherein said resistance heaters of said first heater
3 matrix are adapted to provide a homogeneous thermal
4 environment across tops of said crucibles.

1 17. The heater arrangement according to claim 11,
2 wherein said resistance heaters of said first heater
3 matrix are adapted to provide a homogeneous thermal
4 environment across tops of said crucibles.

1 18. The heater arrangement according to claim 11,
2 wherein said second heater matrix includes at least two
3 legs of at least two of said resistance heaters
4 electrically connected in series and said legs are
5 electrically connected in parallel.

1 19. The heater arrangement according to claim 11,
2 further comprising a second power source connected to the
3 second heater matrix.

1 20. The heater arrangement according to claim 1,
2 wherein said individual growth stations each have an
3 insulating container generally surrounding said crucible

4 and substantially thermally isolating said crucible from
5 other individual growth stations.

1 21. The heater arrangement according to claim 1,
2 wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired
5 thermal environments.

1 22. The heater arrangement according to claim 4,
2 wherein said heaters further comprise:
3 a plurality of bends in the flow paths, and
4 at least one slot extension, extending from said at
5 least one slot into one of the bends, the slot extension
6 acting to decrease the cross-sectional area of the flow
7 path at the bend thereby restricting the flow path and
8 increasing the electrical resistance of the flow path at
9 the bend.

1 23. The heater arrangement according to claim 1,
2 wherein at least one of said resistance heaters having an
3 outer diameter and a bottom surface of the corresponding
4 crucible having an outer diameter, a ratio of the outer
5 diameter of the resistance heater to the outer diameter
6 of the bottom surface of the crucible is at least 1.2.

1 24. A crystal growth furnace comprising:

2 a plurality of individual growth stations each
3 having a crucible;
4 a first heater matrix including at least two
5 resistance heaters electrically connected in series or
6 parallel, each of the individual growth stations having
7 at least one of said resistance heaters associated
8 therewith and located near said crucible; and
9 a power source connected to the first heater matrix.

1 25. The crystal growth furnace according to claim
2 24, wherein said resistance heaters are located below
3 said crucibles.

1 26. The crystal growth furnace according to claim
2 25, wherein said resistance heaters are adapted to
3 provide a thermal gradient across a bottom of said
4 crucibles.

1 27. The crystal growth furnace according to claim
2 26, wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired
5 thermal environments, said flow paths having cross-
6 sections of varying area to obtain said thermal gradient.

1 28. The heater arrangement according to claim 27,
2 wherein said heaters further comprise:
3 a plurality of bends in the flow paths, and

4 at least one slot extension, extending from said at
5 least one slot into one of the bends, the slot extension
6 acting to decrease the cross-sectional area of the flow
7 path at the bend thereby restricting the flow path and
8 increasing the electrical resistance of the flow path at
9 the bend.

1 29. The heater arrangement according to claim 24,
2 wherein at least one of said resistance heaters having an
3 outer diameter and a bottom surface of the corresponding
4 crucible having an outer diameter, a ratio of the outer
5 diameter of the resistance heater to the outer diameter
6 of the bottom surface of the crucible is at least 1.2.

1 30. The crystal growth furnace according to claim
2 24, wherein said resistance heaters are located above
3 said crucibles.

1 31. The crystal growth furnace according to claim
2 30, wherein said resistance heaters are adapted to
3 provide a homogeneous thermal environment across a top of
4 said crucibles.

1 32. The crystal growth furnace according to claim
2 31, wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired
5 thermal environments, said flow paths having cross-

6 sections of generally constant area to obtain said
7 homogeneous thermal environment.

1 33. The crystal growth furnace according to claim
2 24, wherein said first heater matrix includes at least
3 two legs of at least two of said resistance heaters
4 electrically connected in series and said legs are
5 electrically connected in parallel.

1 34. The crystal growth furnace according to claim
2 24, wherein said resistance heaters are adapted to
3 provide similar thermal environments for said individual
4 growth stations.

1 35. The crystal growth furnace according to claim
2 24, wherein said resistance heaters are adapted to
3 provide different thermal environments for said
4 individual growth stations.

1 36. The crystal growth furnace according to claim
2 24, further comprising a second heater matrix including
3 at least two resistance heaters electrically connected in
4 series or parallel, wherein said second heater matrix is
5 separate from said first heater matrix and each of said
6 individual growth stations has at least one of said
7 resistance heaters of said second heater matrix
8 associated therewith and located near said crucible.

1 37. The crystal growth furnace according to claim
2 36, wherein said resistance heaters of said second heater
3 matrix are located below said crucibles.

1 38. The crystal growth furnace according to claim
2 37, wherein said resistance heaters of said second heater
3 matrix are adapted to provide a thermal gradient across a
4 bottom of said crucibles.

1 39. The crystal growth furnace according to claim
2 37, wherein said resistance heaters of said first heater
3 matrix are located above said crucibles.

1 40. The crystal growth furnace according to claim
2 39, wherein said resistance heaters of said second heater
3 matrix are adapted to provide a thermal gradient across a
4 bottom of said crucibles.

1 41. The crystal growth furnace according to claim
2 40, wherein said resistance heaters of said first heater
3 matrix are adapted to provide a homogeneous thermal
4 environment across a top of said crucibles.

1 42. The crystal growth furnace according to claim
2 36, wherein said resistance heaters of said first heater
3 matrix are adapted to provide a homogeneous thermal
4 environment across a top of said crucibles.

1 43. The crystal growth furnace according to claim
2 36, wherein said second heater matrix includes at least
3 two legs of at least two of said resistance heaters
4 electrically connected in series and said legs are
5 electrically connected in parallel.

1 44. The crystal growth furnace according to claim
2 36, further comprising a second single power source
3 connected to the second heater matrix.

1 45. The crystal growth furnace according to claim
2 24, wherein said individual growth stations each have an
3 insulating container generally surrounding said crucible
4 and substantially thermally isolating said crucible from
5 other individual growth stations.

1 46. The crystal growth furnace according to claim
2 24, wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired
5 thermal environments.

1 47. A heater arrangement for a crystal growth
2 furnace comprising:
3 a plurality of individual growth stations each
4 having a crucible;
5 a first heater matrix including at least two legs
6 electrically connected in parallel, each of said legs

7 having at least two resistance heaters electrically
8 connected in series, each of said individual growth
9 stations having at least one of said resistance heaters
10 of said first heater matrix associated therewith and
11 located near said crucible; and

12 a second heater matrix including at least two legs
13 electrically connected in parallel, each of said legs
14 having at least two resistance heaters electrically
15 connected in series, wherein said second heater matrix is
16 separate from said first heater matrix and each of said
17 individual growth stations has at least one of said
18 resistance heaters of said second heater matrix
19 associated therewith and located near said crucible.

1 48. The heater arrangement according to claim 47,
2 wherein said resistance heaters of said second heater
3 matrix are located below said crucibles.

1 49. The heater arrangement according to claim 48,
2 wherein said resistance heaters of said second heater
3 matrix are adapted to provide a thermal gradient across
4 bottoms of said crucibles.

1 50. The heater arrangement according to claim 49,
2 wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired

5 thermal environments, said flow paths having cross-
6 sections of varying area to obtain said thermal gradient.

1 51. The heater arrangement according to claim 50,
2 wherein said heaters further comprise:

3 a plurality of bends in the flow paths, and
4 at least one slot extension, extending from said at
5 least one slot into one of the bends, the slot extension
6 acting to decrease the cross-sectional area of the flow
7 path at the bend thereby restricting the flow path and
8 increasing the electrical resistance of the flow path at
9 the bend.

1 52. The heater arrangement according to claim 47,
2 wherein at least one of said resistance heaters having an
3 outer diameter and a bottom surface of the corresponding
4 crucible having an outer diameter, a ratio of the outer
5 diameter of the resistance heater to the outer diameter
6 of the bottom surface of the crucible is at least 1.2.

1 53. The heater arrangement according to claim 48,
2 wherein said resistance heaters of said first heater
3 matrix are located above said crucibles.

1 54. The heater arrangement according to claim 53,
2 wherein said resistance heaters of said second heater
3 matrix are adapted to provide a thermal gradient across
4 bottoms of said crucibles.

1 55. The heater arrangement according to claim 54,
2 wherein said resistance heaters of said first heater
3 matrix are adapted to provide a homogeneous thermal
4 environment across tops of said crucibles.

1 56. The heater arrangement according to claim 47,
2 wherein said resistance heaters of said first heater
3 matrix are adapted to provide a homogeneous thermal
4 environment across tops of said crucibles.

1 57. The heater arrangement according to claim 56,
2 wherein said resistance heaters comprise sheets of
3 resistive material cut to define electrical flow paths
4 having predetermined resistances for obtaining desired
5 thermal environments, said flow paths having cross-
6 sections of generally constant area to obtain said
7 homogeneous thermal environment.

1 58. The heater arrangement according to claim 47,
2 wherein said first and second heater matrices are adapted
3 to provide similar thermal environments for said
4 individual growth stations.

1 59. The heater arrangement according to claim 47,
2 wherein said first and second heater matrices are adapted
3 to provide different thermal environments for said
4 individual growth stations.

1 60. The heater arrangement according to claim 47,
2 further comprising separate first and second single power
3 sources connected to said first and second heater
4 matrices respectively.

1 61. The heater arrangement according to claim 47,
2 wherein said individual growth stations each have an
3 insulating container generally surrounding said crucible
4 and substantially thermally isolating said crucible from
5 other individual growth stations.

1 62. The heater arrangement according to claim 47,
2 wherein said resistance heaters of said first and second
3 heater matrices comprise sheets of resistive material cut
4 to define electrical flow paths having predetermined
5 resistances for obtaining desired thermal environments.

1 63. A heater arrangement for a crystal growth
2 furnace comprising:
3 a plurality of individual growth stations each
4 having a crucible and an insulating container generally
5 surrounding said crucible and substantially thermally
6 isolating said crucible from other individual growth
7 stations;
8 a first heater matrix including at least two legs
9 electrically connected in parallel, each of said legs
10 having at least two resistance heaters electrically

11 connected in series, each of said individual growth
12 stations having at least one of said resistance heaters
13 of said first heater matrix associated therewith, said
14 resistance heaters of said first heater matrix being
15 located above said crucible and adapted to provide a
16 homogeneous temperature across tops of said crucibles;
17 a second heater matrix including at least two legs
18 electrically connected in parallel, each of said legs
19 having at least two resistance heaters electrically
20 connected in series, said second heater matrix being
21 separate from said first heater matrix and each of said
22 individual growth stations having at least one of said
23 resistance heaters of said second heater matrix
24 associated therewith, said resistance heaters of said
25 second heater matrix being located below said crucible
26 and adapted to provide a temperature gradient across
27 bottoms of said crucibles; and
28 a power source connected to said first and second
29 heater matrices.

1 64. The heater arrangement according to claim 63,
2 wherein said power source includes separate first and
3 second power sources for said first and second heater
4 matrices respectively.

1 65. The heater arrangement according to claim 63,
2 wherein said resistance heaters of said first and second
3 heater matrices comprise sheets of resistive material cut

4 to define electrical flow paths having predetermined
5 resistances for obtaining desired thermal environments.

1 66. The heater arrangement according to claim 65,
2 wherein said heaters further comprise:

3 a plurality of bends in the flow paths, and
4 at least one slot extension, extending from said at
5 least one slot into one of the bends, the slot extension
6 acting to decrease the cross-sectional area of the flow
7 path at the bend thereby restricting the flow path and
8 increasing the electrical resistance of the flow path at
9 the bend.

1 67. The heater arrangement according to claim 66,
2 wherein at least one of said resistance heaters having an
3 outer diameter and a bottom surface of the corresponding
4 crucible having an outer diameter, a ratio of the outer
5 diameter of the resistance heater to the outer diameter
6 of the bottom surface of the crucible is at least 1.2.

1 68. A resistance heater for a crystal growth
2 furnace, the resistance heater being located below a
3 crucible and being adapted to provide a thermal gradient
4 across a bottom surface of the crucible, the resistance
5 heater comprising:

6 a sheet of resistive material,
7 a least one slot in the resistive sheet to define an
8 electrical flow path, the flow path having predetermined

9 electrical resistances for obtaining desired thermal
10 environments, said flow paths having cross-sections of
11 varying area to obtain said thermal gradient,
12 a plurality of bends in the flow path, and
13 at least one slot extension, extending from said at
14 least one slot into one of the bends, the slot extension
15 acting to decrease the cross-sectional area of the flow
16 path at the bend thereby restricting the flow path and
17 increasing the electrical resistance of the flow path at
18 the bend.

1 69. The resistance heater according to claim 68,
2 wherein the cross-sectional area of the flow path is
3 varied by a varying width of the flow path.

1 70. The resistance heater according to claim 68,
2 wherein the cross-sectional area is varied by a varying
3 thickness of the heater.

1 71. The resistance heater according to claim 68,
2 the resistance heater having an outer diameter and the
3 bottom surface of the crucible having an outer diameter,
4 wherein a ratio of the outer diameter of the resistance
5 heater to the outer diameter of the bottom surface of the
6 crucible is at least 1.2.

1 72. The resistance heater according to claim 68,
2 wherein the resistance heater is adapted so that the

3 thermal gradient has a substantially uniform temperature
4 change across a radius of the heater of between 12°C per
5 inch and 15°C per inch.

1 73. The resistance heater according to claim 68,
2 wherein the resistance heater is adapted so that the
3 thermal gradient of the heater produces a substantially
4 uniform temperature change across a radius of a bottom
5 surface of the crucible of between 5.5°C per inch and
6 7.5°C per inch.

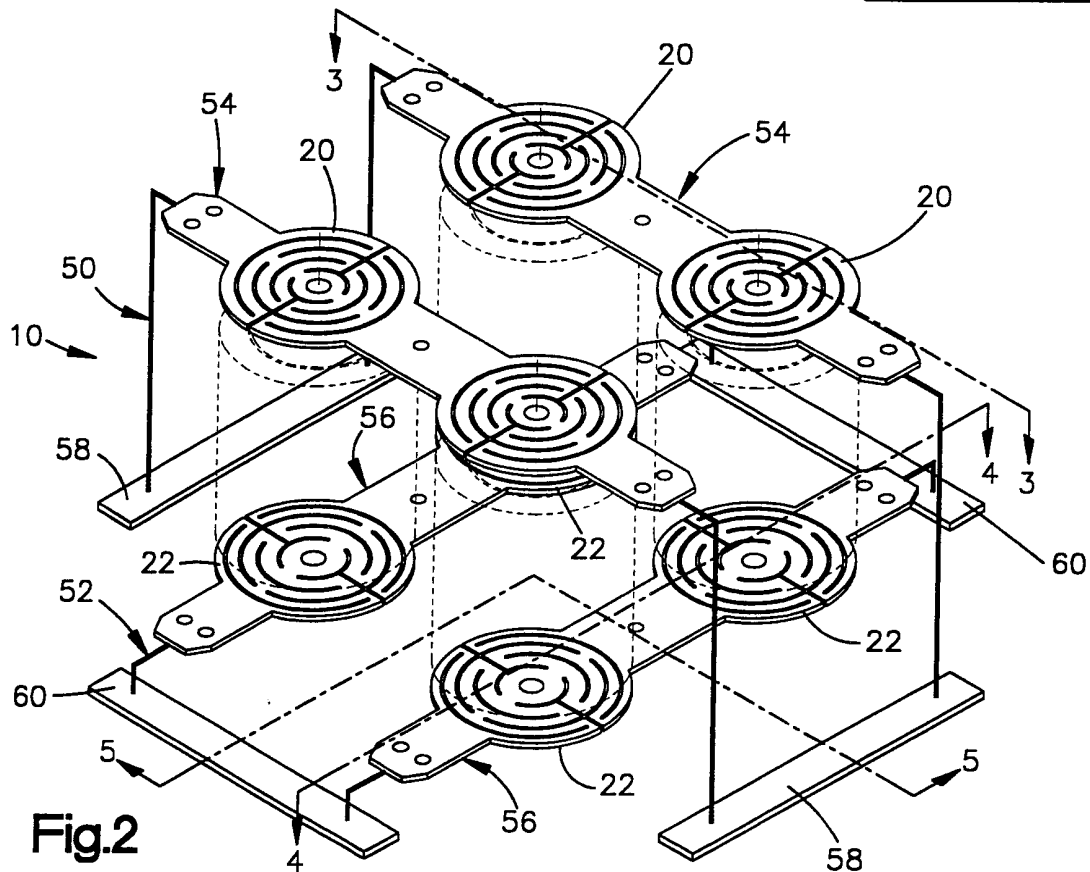
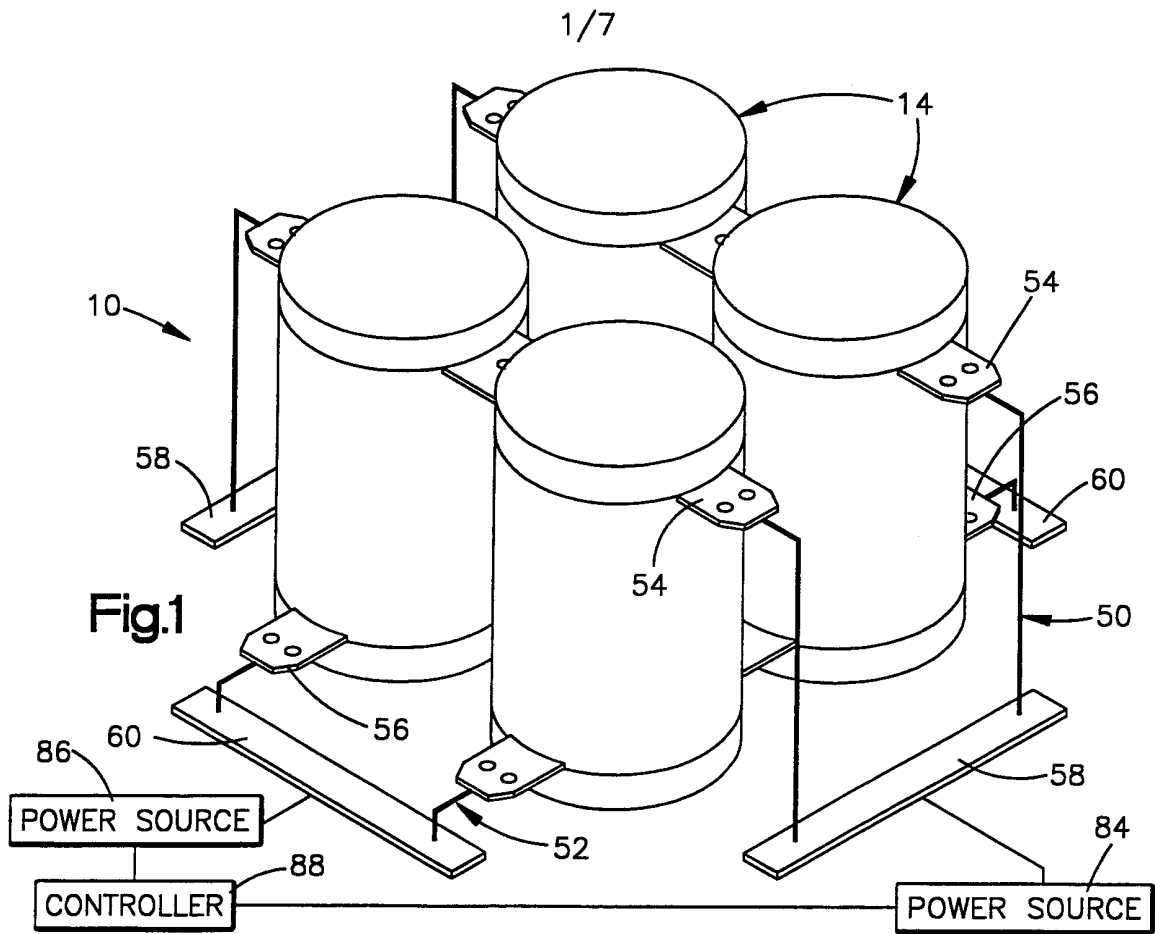
1 74. The resistance heater according to claim 68,
2 wherein a width of an outermost semi-annular section of
3 the flow path is approximately one half of a width of an
4 innermost semi-annular section of the flow path.

1 75. The resistance heater according to claim 68,
2 wherein at least one of the plurality of bends connects
3 two semi-annular sections of the flow path at ends of the
4 sections, the bend having a width that is approximately
5 equal to one half of the sum of the widths of the two
6 sections divided by 1.79.

1 76. The resistance heater according to claim 68,
2 wherein at least one of the plurality of bends connects
3 two semi-annular sections of the flow path along the
4 circumference of the sections, the bend having a width

5 that is approximately equal to the sum of the widths of
6 the two sections divided by 1.79.

1 77. The resistance heater according to claim 71,
2 and further including a top resistance heater located
3 above the crucible having a ratio of the outer diameter
4 of the top heater to the outer diameter of a top surface
5 of the crucible of at least 1.2.



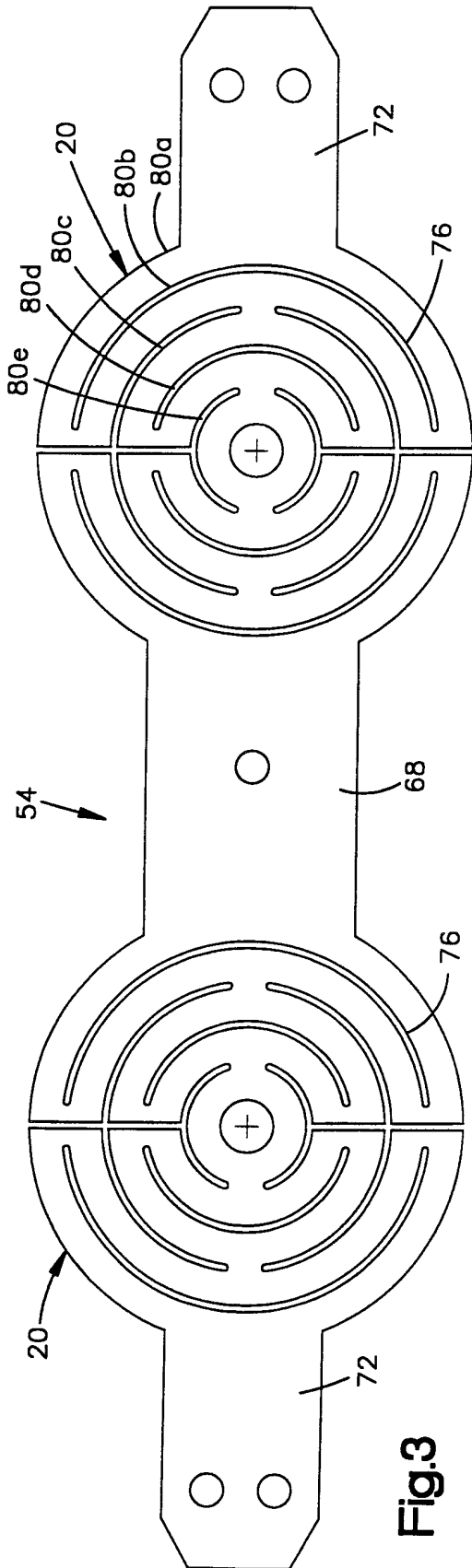


Fig.3

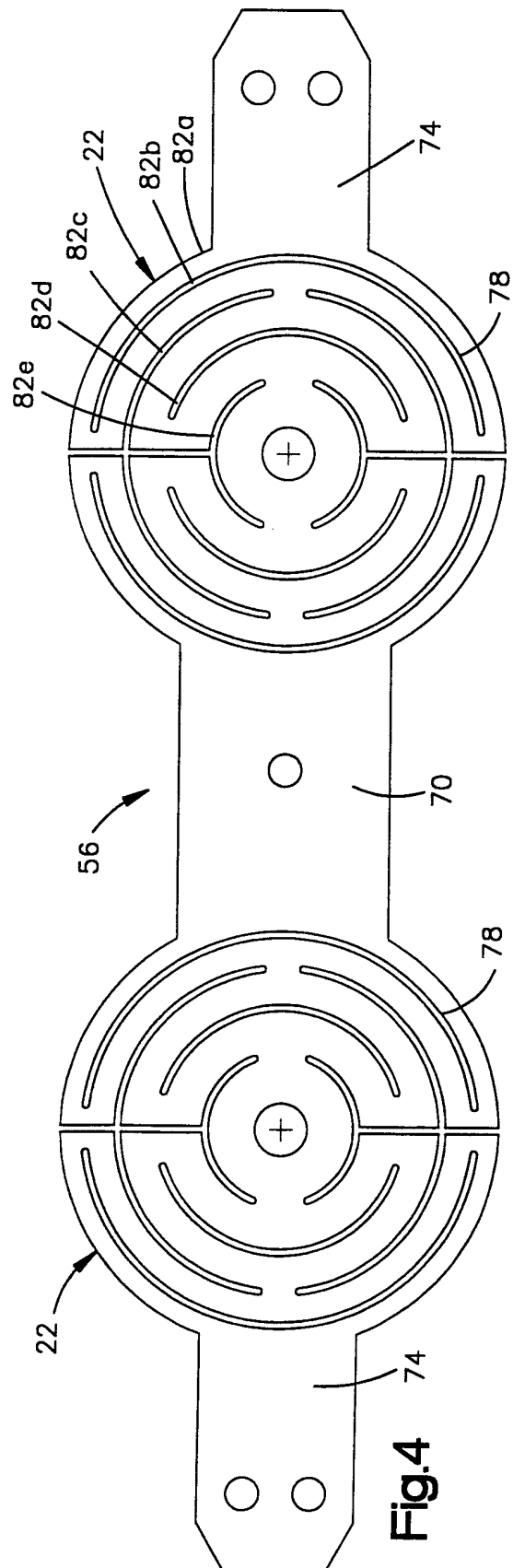


Fig.4

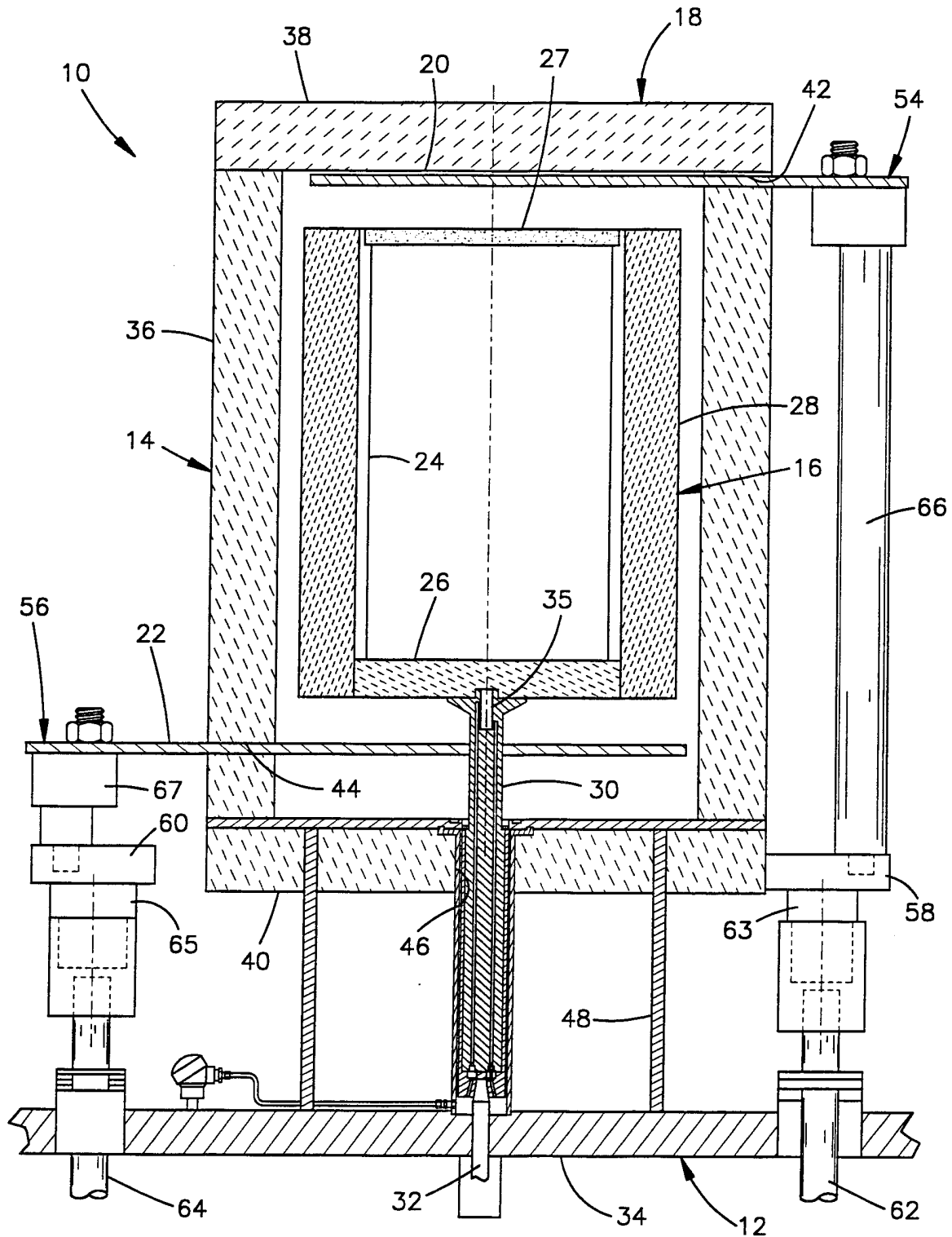


Fig.5

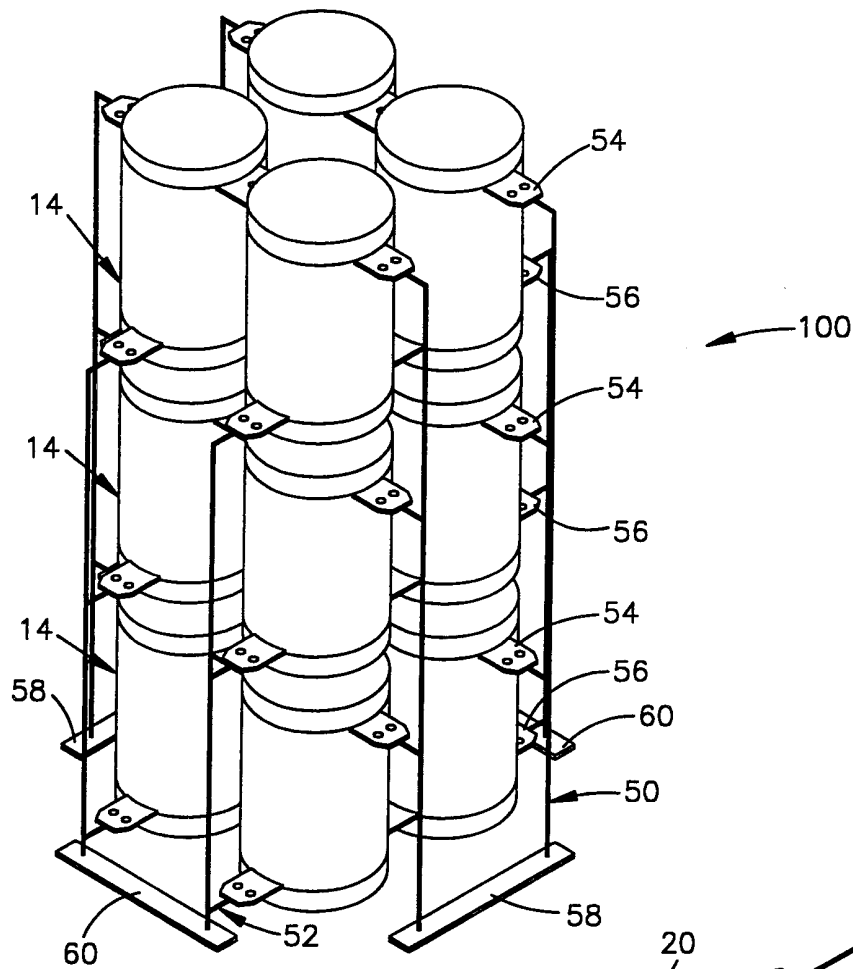


Fig.6

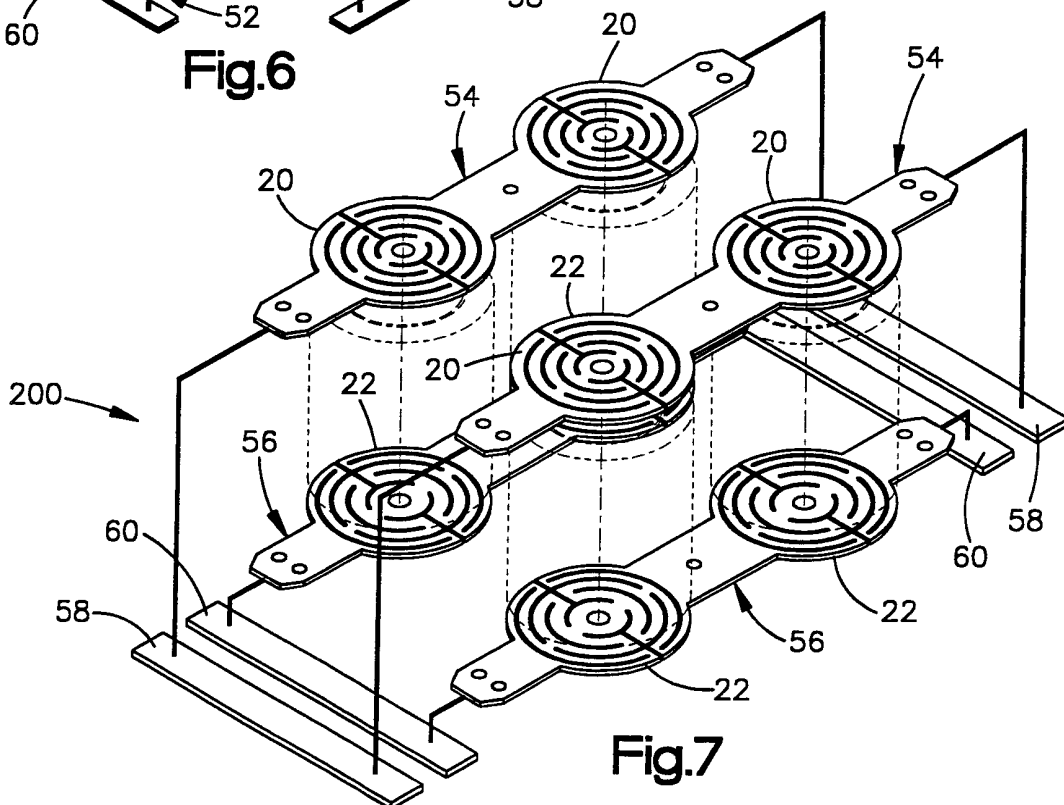


Fig.7

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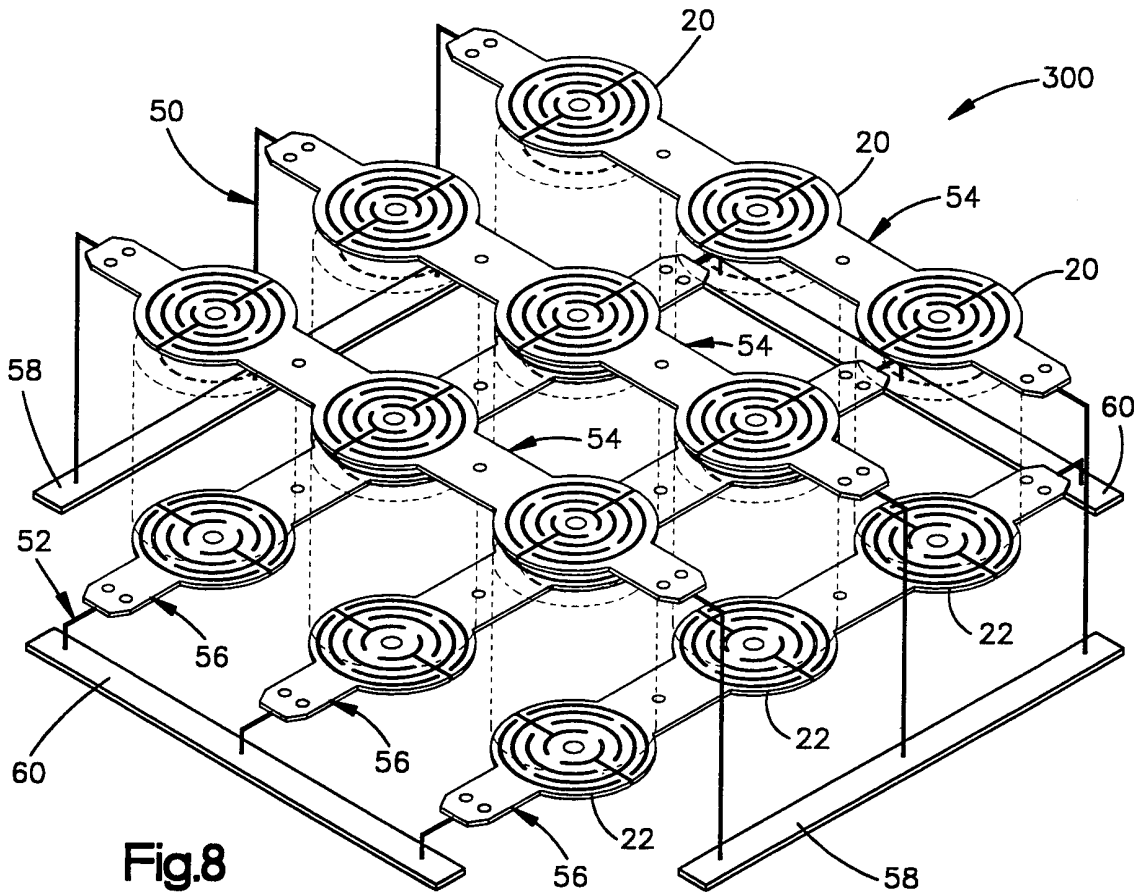


Fig.8

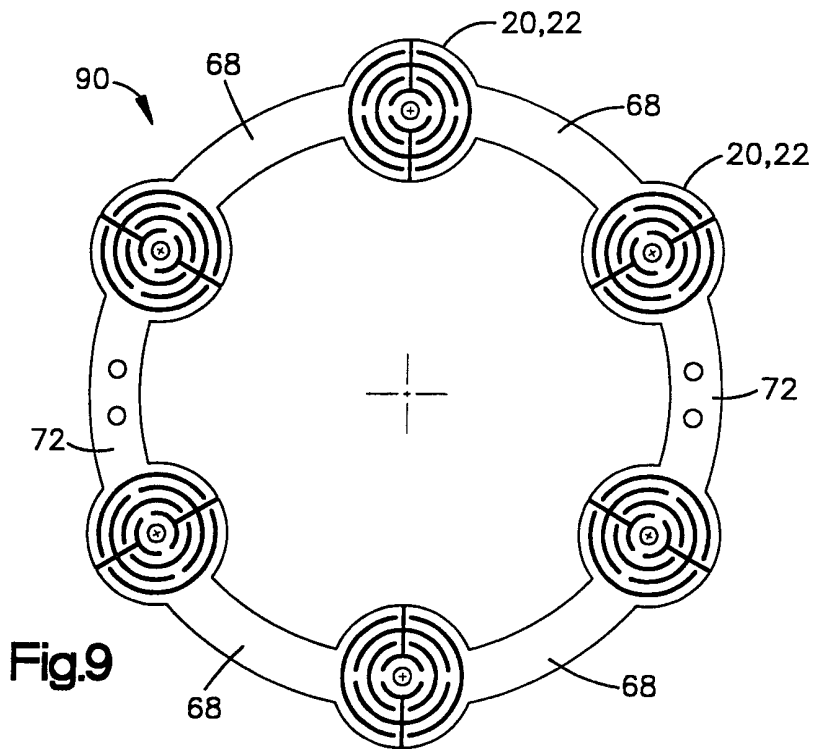


Fig.9

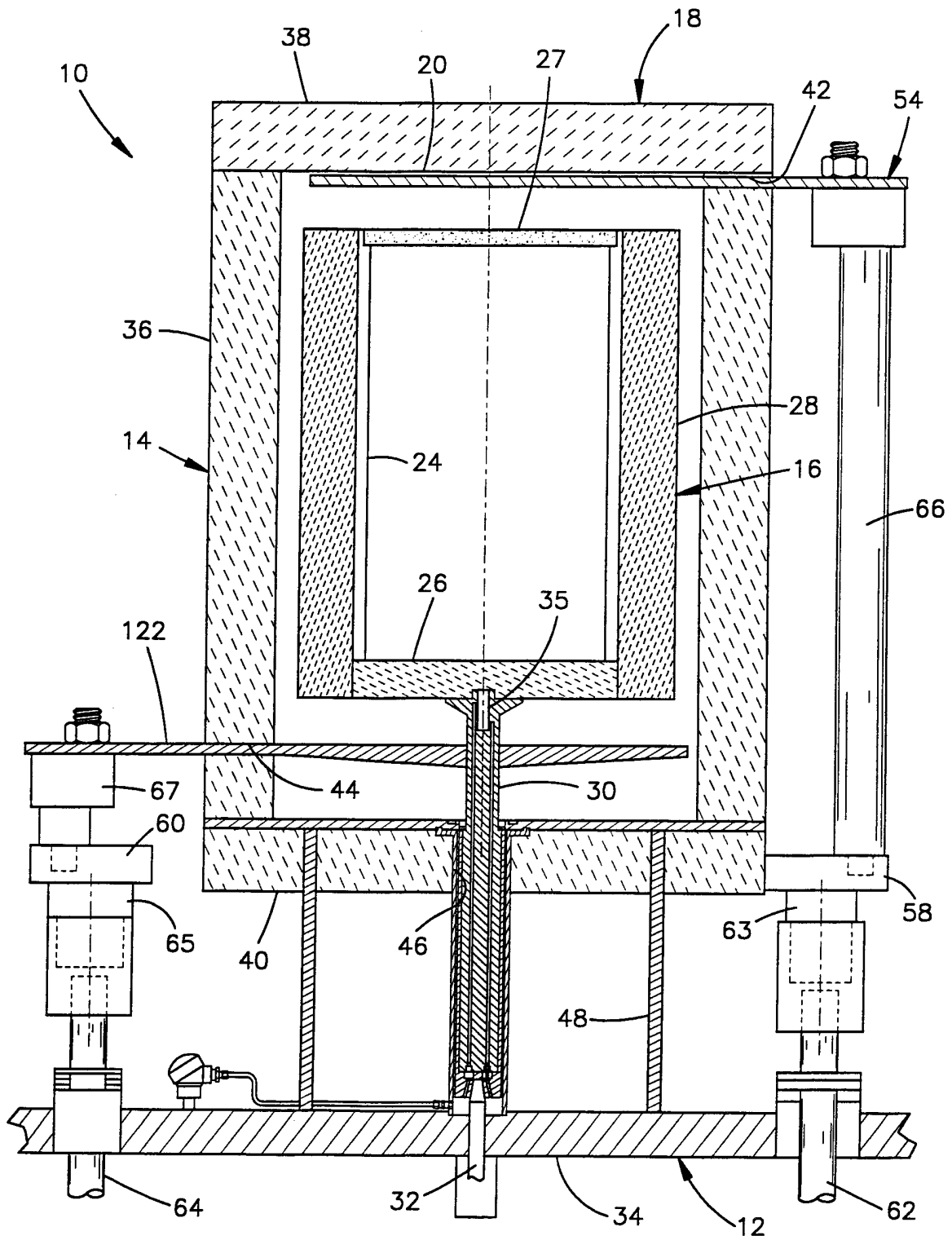


Fig.10

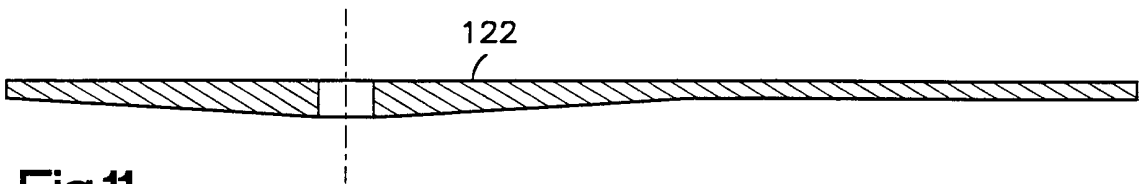


Fig.11

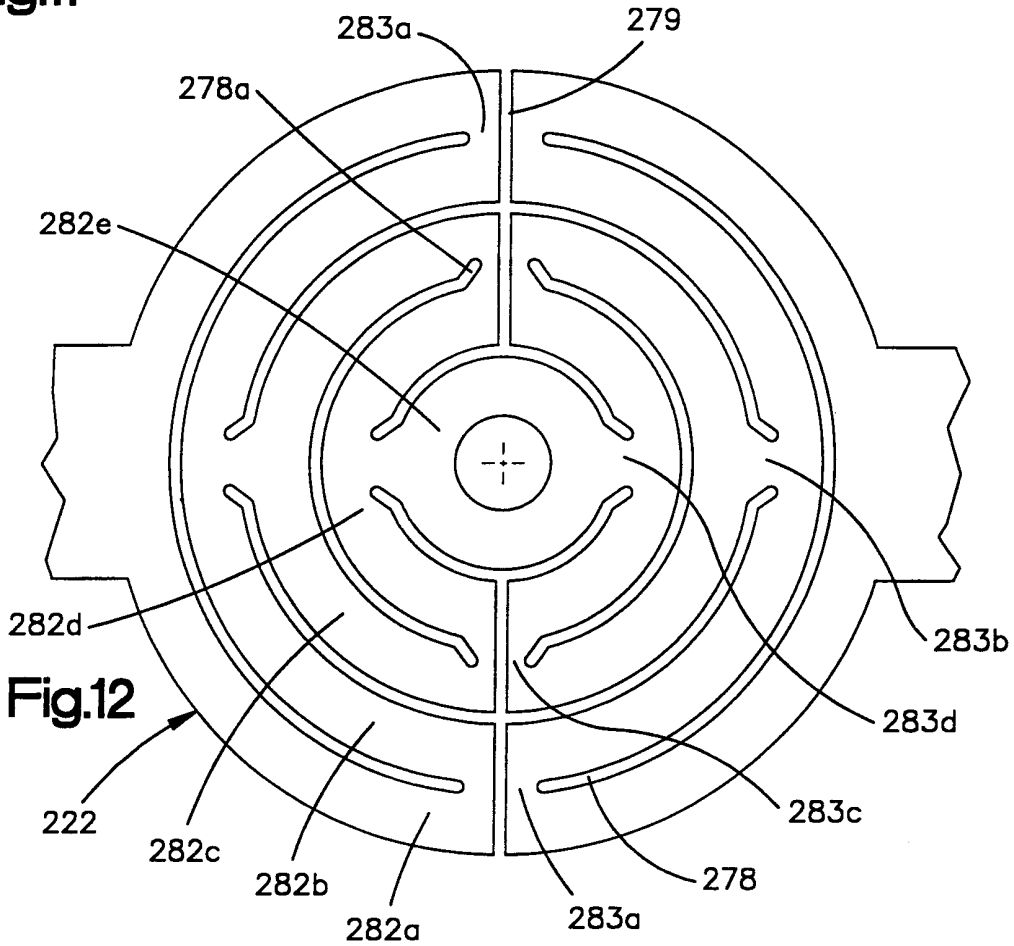


Fig.12

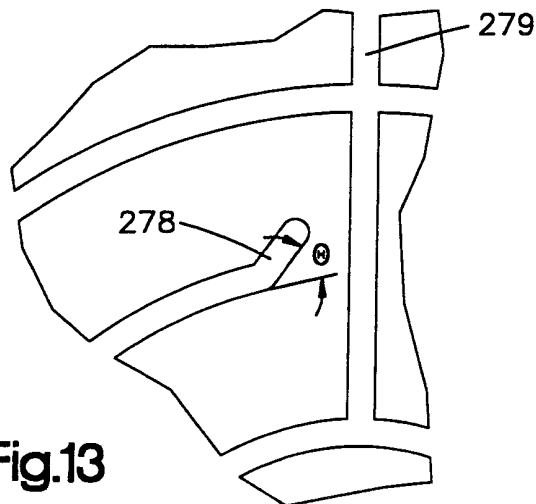


Fig.13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/17667

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : C30B 35/00

US CL : 117/200, 206

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)

U.S. : 117/200-224

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 practicable, search terms used)

IBMTB, DERWENT, JPO, EPO, USPAT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,865,554 A (WENCKUS et al.) 11 February 1975	1-77
Y	US 3,961,905 A (RICE) 08 June 1976, Abstract	1-77
A	US 4,118,197 A (MACKINTOSH et al.) 03 October 1978	1-77
Y	US 4,158,038 A (JEWETT) 12 June 1979 Abstract	1-77
Y	US 4,282,184 A (FIEGL et al.) 04 August 1981, Fig. 1	1-77
Y	US 4,521,272 A (GAULT) 04 June 1985, Abstract	1-77

 Further documents are listed in the continuation of Box C.
 See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier document published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search

28 AUGUST 2000

Date of mailing of the international search report

04 OCT 2000

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/17667

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,087,429 A (KAMIO et al.) 11 February 1992, Figs. 1, 2.	1-77
Y	US 5,137,699 A (AZAD) 11 August 1992, Fig. 1.	1-77
Y	US 5,162,072 A (AZAD) 10 November 1992, Figs. 1,2.	1-77
A	US 5,616,175 A (WALSH) 01 April 1997, Fig. 1, Col. 1	1-77
Y	US 5,641,354 A (SAKAUCHI et al.) 24 June 1997, Fig. 1	1-77
Y	US 5,824,149 A (LI) 20 October 1998, Abstract	1-77
Y	US 6,093,913 A (SCHRENKER et al.) 25 July 2000, Figs. 1,2, cols. 1-4.	1-77