April 30, 1968 SHO NAKANUMA 3,381,114

DEVICE FOR MANUFACTURING EPITAXIAL CRYSTALS

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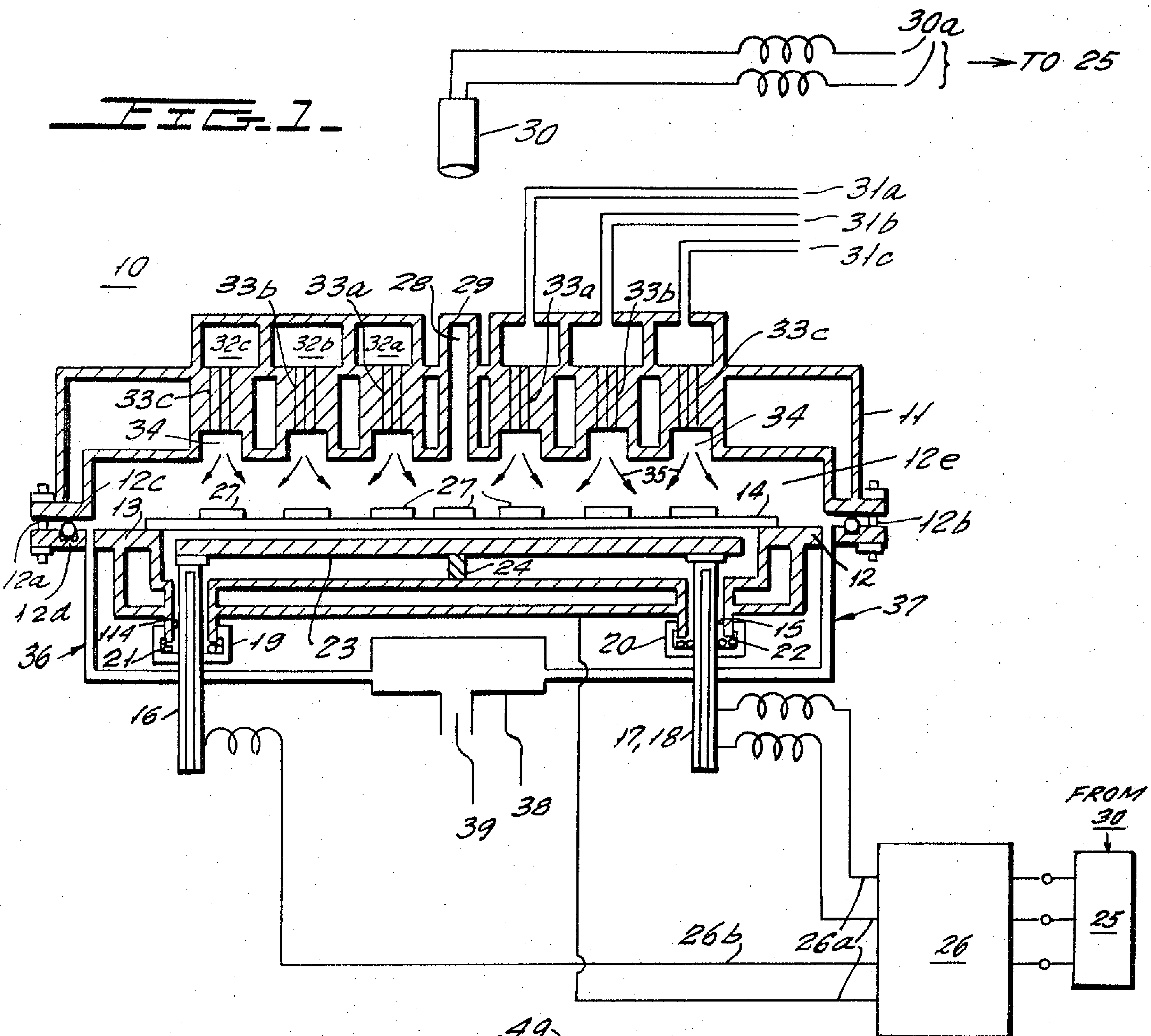
FIG. 1



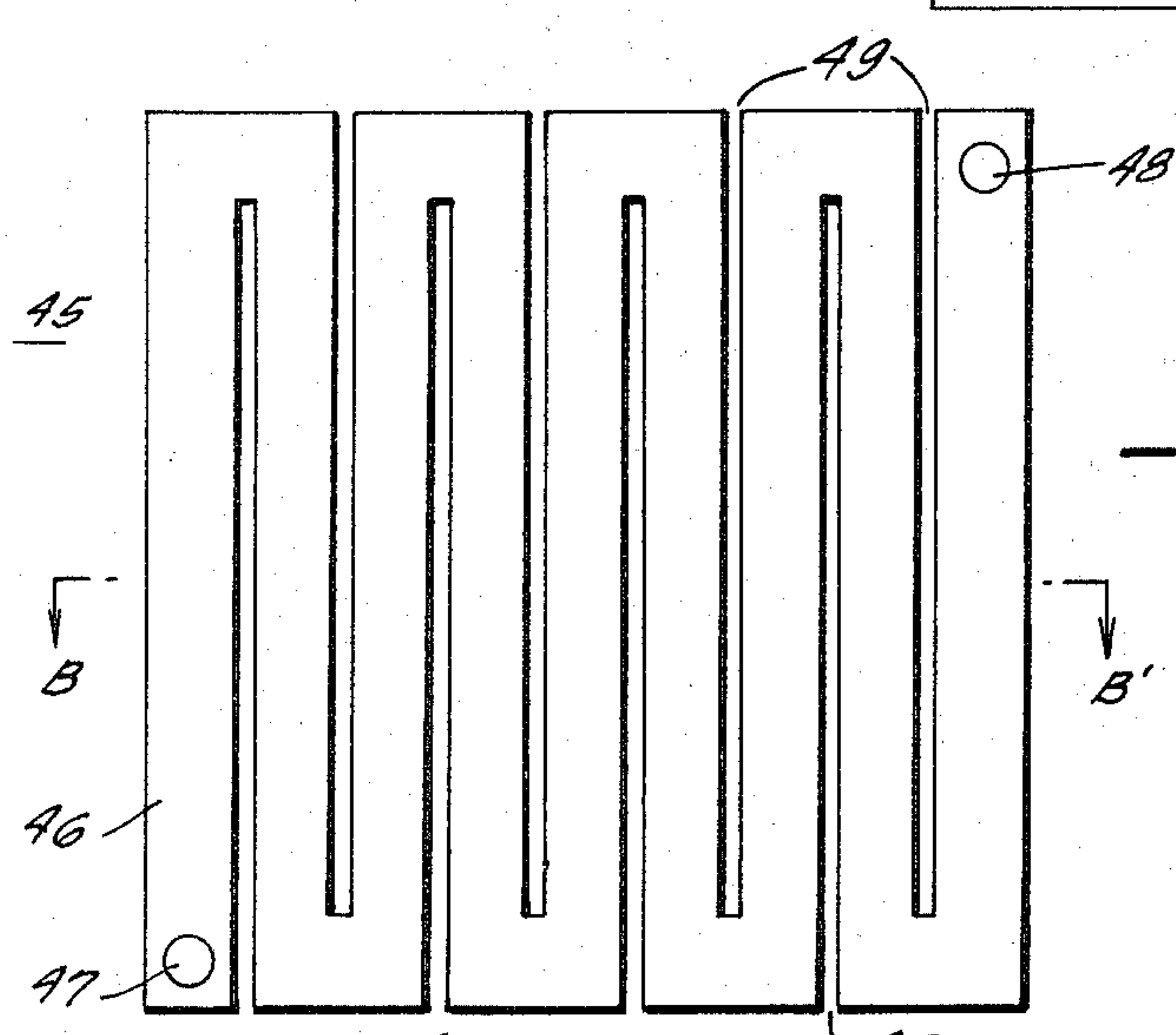


FIG. 3a

PRIOR ART

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FIG. 3b.

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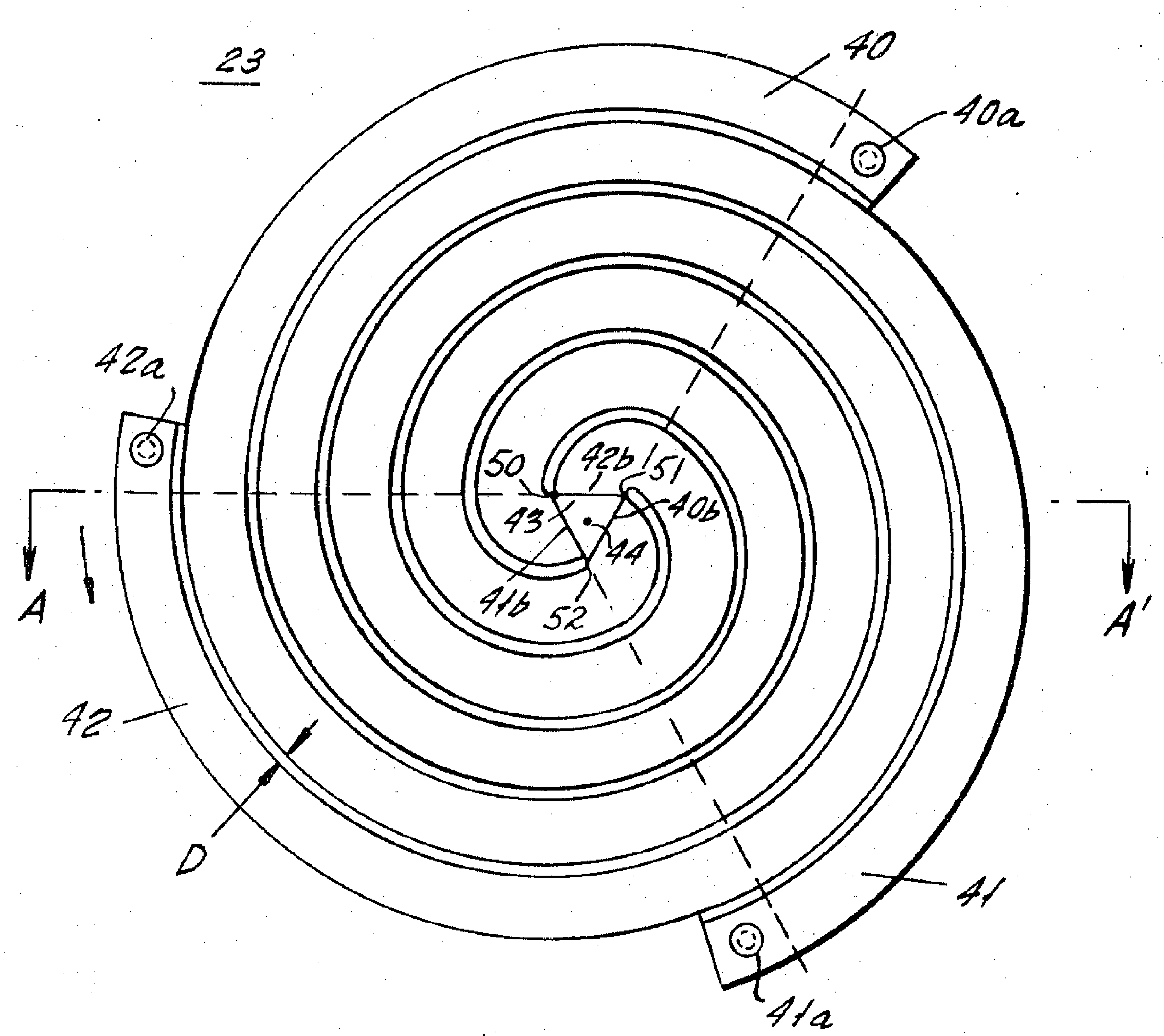
FIG. 2a



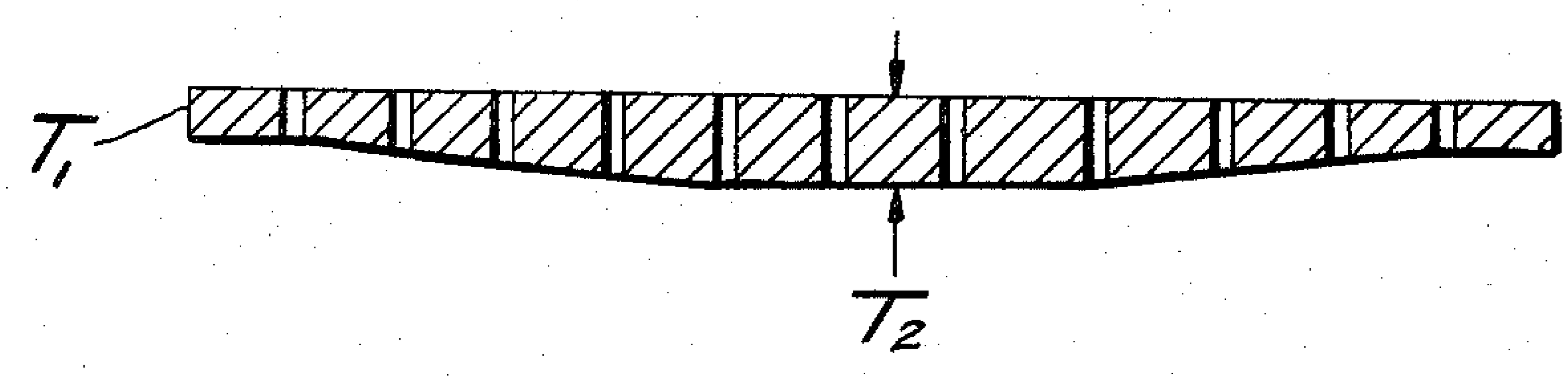


FIG. 2b

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DEVICE FOR MANUFACTURING EPITAXIAL CRYSTALS

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ABSTRACT OF THE DISCLOSURE

This invention teaches an apparatus for use in producing crystals preferably of the epitaxial type which enables the mass production of such crystals having uniform quality and uniform operating characteristics. The apparatus is comprised of a housing having first and second halves which have cylindrical mating sides to form a substantially cylindrical-shape reaction chamber therein. A first half of the chamber is provided with inlet ports arranged in symmetrical fashion for the introduction of gaseous material in an extremely uniform fashion within the chamber, which gaseous materials are employed in the epitaxial growth process. The remaining half of the housing is provided with outlet ports likewise arranged in a symmetrical fashion for removing exhausting gases from the chamber. A gas trap is provided between the outlet ports and the exterior of the housing.

A novel heating element is provided within the reaction chamber and is formed of a plurality of spiral shaped heating sections spiralling outwardly from a central point of the heating element. Each of the sections are substantially identical in configuration and have substantially continually decreasing cross-sections from the center of each section outward to assure uniform heat level within the reaction chamber during the growth process. Preferably three sections form the heating element with the outward ends thereof being coupled to suitable connections of a three-phase power system. The center points of each of the spiral sections are electrically joined at the center of the heating element. While a delta-type three-phase system may be employed, it is likewise advantageous to utilize a Y-type three-phase power system having its center point grounded and electrically connected to the center point of the heating element. The heating element has a first surface which is substantially flat for the purpose of positioning and supporting crystal substrates used in the growth process. The symmetrical aspect of the housing and its reaction chamber assures the production of crystals having uniform operating characteristics.

The instant invention relates to crystal manufacture and more particularly to apparatus for producing crystals preferably of the epitaxial type which apparatus permits the mass production of epitaxial wafers all being of uniform quality and having uniform operating characteristics.

The widespread use of devices of the semiconductor type such as, for example, transistors, diodes, rectifiers and the like, have placed extremely large demands for epitaxial type wafers, which demands have become so great that the epitaxial crystals available must be produced in large quantities and even more importantly must have superior operating characteristics, which characteristics are uniform among the devices produced. While great emphasis has been placed upon the production of epitaxial crystals through mass production techniques, and while it has been quite practical to manufacture epitaxial crystals in accordance with conventional techniques, an extreme amount of difficulties have been experienced in those attempts to manufacture epitaxial wafers in large quantities

wherein the wafers produced have extremely uniform quality.

The instant invention provides a novel apparatus and method for producing epitaxial crystals of high uniform quality through mass production techniques by providing a chamber of unique designs in which such crystals are formed.

The instant invention is comprised of a substantially metal housing which defines a chamber therein for receiving a quartz disc and a plurality of wafer-like crystal substrates for the epitaxial growth to take place. The chamber is a substantially circular or symmetric container, having symmetrically located inlets communicating with associated nozzles through manifolds and capillary tubes for the purpose of introducing the necessary gaseous materials employed during the growth process. A heater element is positioned beneath the quartz disc and is so designed as to provide constant heat in a uniform manner within the entire chamber. The heating element is preferably formed of a suitable carbon material physically arranged so as to define three substantially concentric spirals all of which lie substantially in a plane and which are energized by a three-phase power source. The thickness of the heater assembly, in its cross-section, resembles a convex lens structure and is so designed as to generate extremely uniform heat throughout the entire chamber region. The physical configuration of the heater assembly, coupled with the fact that it is powered by a three-phase source, provides an extremely efficient heating apparatus in which the temperature throughout the entire chamber is substantially constant. The nozzles through which the gaseous material is introduced into the chamber are also arranged in a symmetrical manner so as to be evenly distributed within the chamber, thereby cooperating with the heater assembly to yield epitaxially grown crystals, all of which have substantially identical characteristics.

The heater element may preferably be designed by first setting out an equilateral triangle and locating its center of gravity. The sides of the triangle are then extended outwardly so as to effectively extend as radii from the center of gravity point. A circular arc may then be drawn from one vertex of the triangle so as to circumscribe approximately one-third of a circumference so as to intersect at the next extended side of a triangle which lies approximately 120° away from the first radial line. Each succeeding arc of a third of a circle may be drawn in a like manner until the complete spiral is drawn. The convex shape of the spiral heating element is established by increasing the cross-sectional area towards the center of the spiral relative to the cross-sectional area near the periphery of the spiral element so that the entire heater element generates even heat over the entire surface of the heater element. The use of a heater element energized by a three-phase power source is advantageous since the load presented to the power source is more uniform and hence more efficient.

By providing symmetrical disposition for the outlets which introduce the gaseous mixtures into the chamber, a very uniform feeding of the gaseous mixtures results, thereby ultimately resulting in the production of epitaxially grown crystals having extremely uniform characteristics.

It is therefore one object of the instant invention to provide novel means for producing epitaxially grown crystals in large quantities wherein the crystals so grown have extremely uniform characteristics.

A further object of the instant invention is to provide apparatus for epitaxially growing a large number of crystals, which apparatus employs a spiral heater element energized by a three-phase power source to provide extremely uniform heating within the chamber in which the crystals are grown.

Another object of the instant invention is to provide apparatus for epitaxially growing a large number of crystals, which apparatus employs a spiral heater element energized by a three-phase power source to provide extremely uniform heating within the chamber in which the crystals are grown wherein the heater element has a convex configuration in order to provide uniform heating over the entire surface of the heater element.

Still another object of the instant invention is to provide apparatus for epitaxially growing a large number of crystals, which apparatus employs a spiral heater element energized by a three-phase power source to provide extremely uniform heating within the chamber in which the crystals are grown, wherein the spiral heater element is symmetrical about its central axis in order to provide extremely uniform heat for the epitaxial growth process.

Still another object of the instant invention is to provide novel apparatus for epitaxially growing crystals comprised of a chamber having gas inlet ports arranged symmetrically about the chamber to provide uniform flow of gases into the chamber in order to yield epitaxially grown crystals having extremely uniform characteristics.

These and other objects will become apparent when reading the accompanying description and drawings in which;

FIGURE 1 is a cross-sectional view of an apparatus employed for the purpose of epitaxially growing crystals in mass quantities and which is designed in accordance with the principles of the instant invention.

FIGURE 2*a* shows the top view of the heater element employed in the apparatus of FIGURE 1.

FIGURE 2*b* is a cross-section of the heater element of FIGURE 2*a* taken along the line A–A'.

FIGURE 3*a* is a top view of a heater element known to the prior art.

FIGURE 3*b* is a cross-section of the heater element of FIGURE 3*a* taken along the line B–B'.

Referring now to the drawings, FIGURE 1 shows apparatus, **10**, employed for the purpose of epitaxially growing crystals and which is designed in accordance with the principles of the instant invention. The apparatus **10** is comprised of a metallic-acid-proof housing, generally comprised of an upper half, **11**, and a lower half, **12**. The two-housing portions are suitably fastened together such as shown at **12*a*** and **12*b***, around the periphery of the housing, but cannot be clearly seen from FIGURE 1. It should be understood that the housing comprised of upper and lower halves **11** and **12**, respectively, when viewed from a top view would have a generally circular configuration.

Spaced slightly inward from the periphery of the upper and lower halves **11** and **12** is a suitable gasket **12*c***, seated within a groove **12*d*** in lower half **12** in order to provide an air-tight chamber **12*e***, which is defined by the housing upper and lower portions **11** and **12**.

The lower housing portion **12** provides a marginal ledge **13** which should be understood to be substantially circular, upon which ledge is supported a quartz disc **14**. The lower housing portion **12** is further provided with suitable openings (only two of which are shown) **114** and **15**, for receiving the electrical terminals **16** and **17** for providing electrical connections between the heater element power source and the heater element, to be more fully described. Since a three-phase power source is used for energization of the heater element, it should be understood that three such openings of the type of openings **14** and **15** should be provided. Each terminal **16** and **17** is insulated from the housing lower portion **12** by the insulating support means **19** and **20**, respectively. Each support means is provided with suitable resilient O-ring structures **21** and **22**, respectively, for hermetically sealing the interior of the housing from the influence of the exterior region surrounding the housing.

The heater element **23** is physically secured to and supported by the electrical terminals **16**, **17** and **18** (it being considered that the terminal **18** lies immediately behind the terminal **17**) so as to lie immediately beneath the quartz disc **14**. The center of the heater element **23** is supported by a metallic support member **24**, which electrically connects the center of the heater element to the housing lower portion **12**. In addition to electrically connecting the center of the heater element to the housing lower portion **12**, member **24** further provides support for the heater element so as to prevent any sagging of the heater element, thereby keeping its spacing between its upper surface and the lower surface of the quartz disc **14** relatively constant.

The heater element **23** is energized by a suitable three-phase power source **25**, which may, for example, be coupled to the heater element through a transformer means **26** having its secondary or output terminals **26*a*** connected to the terminals **16**, **17** and **18**, respectively, and having its terminal at ground potential **26*b***, electrically connected to the housing lower portion **12** which, in turn, is connected to the center of heater element **23** through metallic support member **24**. While the use of a Y-type connection is suggested herein, it should be noted that a three-phase delta connection may be used, if desired. The heater element **23**, when so energized, provides a suitable level of heat within the chamber **12** with the heater element preferably being formed of carbon. In the case where a delta three-phase connection is employed, thus making it unnecessary to ground the center point of the heater element, support **24** may be formed of a suitable insulating material to prevent the heater element from sagging in the center thereof with the insulator material being such as to be insensitive to the heat generated by the heater element.

The quartz disc **14**, which is supported by the ledge **13** of lower housing portion **12**, in turn supports a plurality of single crystal substrates **27** which are arranged in a concentric manner upon quartz disc **14**. In order that the temperature within chamber **12** be clearly determined and regulated, the housing upper portion **11** is provided with a suitable opening **28** which, in turn, is hermetically sealed by a quartz window **29** which is centrally disposed relative to the housing upper portion. The temperature within chamber **12** is detected by means of an optical pyrometer **30**, the output of which is taken across its output terminals **30*a*** and is impressed upon the control input terminal of the heater element power source **25**, for the purpose of automatically controlling the temperature by virtue of controlling the heater current injected into the heater element **23**.

In order to epitaxially grow crystals within the chamber **12** the container upper portion **11** is provided with a plurality of gas inlet means **31*a*–31*c*** which receive vaporized silicon tetrachloride and hydrogen gas and introduce these mixtures into the reaction chamber **12** by means of the annular-shaped manifolds **32*a*–32*c***, respectively. While it cannot be specifically seen from FIGURE 1, it should be understood that each of the manifolds **32*a*–32*c*** has a substantially annular or toroidal shape in conformity with the substantially circular symmetry desired from the overall apparatus.

Each of the manifolds **32*a*–32*c*** has a plurality of capillary tubes **33** extending downwardly from the annular manifolds to provide passage for the gaseous mixtures from the manifolds to the reaction chamber **12**. While it should be understood that each manifold is provided with a fairly substantial number of capillary tubes uniformly arranged around the annular manifold, FIGURE 1 shows only two such capillary tubes for each of the manifolds. For example, the outermost manifold **32*c*** is shown as having two capillary tubes **33*c***. The intermediate manifold **32*b*** is shown as having two capillary tubes **33*b***, and in a like manner the innermost annular-shaped manifold **32*a*** is shown as having two such capillary tubes **33*a***, respectively. Each of the capillary tubes opens to form an associated nozzle **34** in order to distribute the gaseous mixtures in the manner shown by the arrows **35**.

As one preferred method for growing such epitaxial crystals, the vaporized silicon tetrachloride and hydrogen gas mixture decomposes over the silicon single crystal substrates **27**, which have preferably been heated to a temperature of approximately 1250° C., causing the silicon to be extricated, which results in the epitaxial crystal growth upon the substrates **10**.

The gaseous mixture within reaction chamber **12** is preferably exhausted from the chamber by means of a plurality of symmetrically arranged exhaust tubes (only two of which are shown in FIGURE 1) **36** and **37**, which tubes communicate from the reaction chamber **12** to a gas trap **38** in which the gases are collected so as to be ultimately exhausted or removed from the trap outlet **39**.

As has been previously described, it is extremely important that the reaction conditions for each substrate be equal in order to produce epitaxial crystals having a high degree of uniformity in such a mass production apparatus. This requires that each substrate be heated to substantially identical temperatures and secondly, that the flow of the reacting gas mixtures be extremely uniform and symmetrical throughout the chamber. In order to achieve uniform heating of all the crystal substrates, this requires the provision of uniform heating over an extremely large area with a high degree of symmetry. In order to achieve this requirement, it becomes necessary to have a heated area which is as close to being circular as possible. This is accomplished by providing a heater having a spiral configuration such as is shown in FIGURES 2*a* and 2*b*. The heater element **23** shown therein is a substantially spiral arrangement comprised of three individual spirally arranged metallic sections **40**, **41** and **42**, respectively, with each of the spiral sections being separated from the adjacent spiral section by a substantially constant distance D. Each spiral section is provided with a suitable aperture **40*a*–42*a***, respectively, for suitable connection to the electrical terminals **16**, **17** and **18**, respectively, shown in FIGURE 1. Any suitable electrical fastening means may be employed for physically and electrically connecting heater element **23** to the electrical terminals **16–18**.

The individual spiral segments **40–42** are both physically and electrically joined at their innermost ends **40*b*–42*b***, respectively, which define an equilateral triangle **43**, having its center of gravity at **44** from which it can clearly be seen that the spiral segments are very symmetric about the point **44**. It should be understood that the equilateral triangle **43** is not an opening, but is an extension of the spiral section inner ends, being integrally formed with each section so as to electrically connect these sections at their inner ends. Thus, the symmetrical arrangement of the heater element **23** very readily lends itself to connection to a three-phase source of a Y-type configuration with the center of the Y-type configuration being grounded and connected to the center section **43** of the heater element **23** and with the three arms of the Y-configuration being connected across the outer ends of the spiral segments **40–42**, respectively.

Considering a sectional view of the heater element **23** of FIGURE 2*a*, which sectional view is shown in FIGURE 2*b*, it can be seen that the heater element has a configuration substantially analogous to a convex lens cross-section with the thickness at the ends being T_1 and increasing toward the center to a thickness T_2 which is somewhat greater than the thickness T_1. Since the spiral heater element **23** will in general, generate more heat near the central portion thereof, by controlling the cross-sectional area of the spiral sections from the outer ends toward the center thereof, it is thereby possible to regulate the heating gradient along each section so that the outermost cross-sectional areas, being less than the innermost cross-sectional areas, will generate more heat thereby yielding an overall effect of a substantially constant temperature level being present over the entire surface of the heater element **23**. This result is possible due to the fact that the heat generated by a conductive element is related to the cross-sectional area of the heater element.

While the preferred embodiment of the heater element of the instant invention is a substantially circular-shaped spiral arrangement having a convex-lens-like cross-section, it should be understood that a spiral heater element having a rectangular cross-section may be employed which greatly facilitates production of heater elements, but which occurs at a sacrifice to the heating characteristics of the heater element.

FIGURES 3*a* and 3*b* show the conventional carbon heater element **45** of the prior art which is comprised of a single phase heater section **46**, having a substantially square-shaped periphery and arranged in a regular, serpentine fashion, in the manner shown, and having suitable openings **47** and **48** at the extreme ends thereof for connection to a single-phase power source. The slots **49** are provided to form the serpentine configuration for the heater element. The convex lens-like cross-section, shown in FIGURE 2*b*, yields a higher current density near the periphery of the heater element **23** than that obtained in the central portion, thus providing a large heating area having a substantially high degree of symmetry and a substantially uniform temperature distribution far superior to that achieved through the prior art heater element **45**.

It becomes apparent from the manufacturing point of view, as well as from the performance characteristics that a substantially circular-shaped housing is superior to a rectangular or square-shaped housing. Exhaustive experimentation in which substantially identical circular housings were provided with one being provided with a three-phase heater element as shown in FIGURE 2 and a second being provided with a single phase heater element as shown in FIGURE 3, being operated to perform the epitaxial growth operations. From the geometric viewpoint, the heating area of heater element **23** is approximately 1.5 times that of the heating area of element **45**. The area with uniform temperature is approximately two times greater in the heating element **23** over the heating element **45**, thereby accommodating substantially two times as many crystal substrates **27** in an apparatus employing heater element **23** as opposed to an apparatus employing a heater element **45** within a circular container, such as the container formed from the upper and lower portions **11** and **12**, shown in FIGURE 1.

The manner in which a spiral type heater **43** may be formed is as follows:

Firstly, an equilateral triangle having the vertices **50**, **51** and **52**, is drawn, which equilateral triangle has its center of gravity at **44**. The sides **50–52**, **52–51** and **51–50** are extended outwardly in the radial direction. Substantially one-third of a circle with a suitable radius is then drawn about the vertex **50** in the region defined by the extended lines **51–50** and **50–52**, while another third of a circle is drawn about the vertex **52**, with a radius measured substantially from vertex **52** to the inner section between the first circle segment and the extended line **50–52** and in the area defined by the extended lines **50–52** and **52–51**. By continuously repeating this process one member of the three spiral members is drawn. Other sets of spirals can be drawn in a like manner. Another major advantage of the heater element **23** of FIGURES 2*a* and 2*b* is that a three-phase load provides a more uniform load to a power source than does a single-phase load.

The second major objective of the inventive apparatus, being the achievement of extremely uniform and symmetrical flow of the reacting gas mixtures, is achieved by the substantially symmetrical arrangement of both the annular manifolds and their accompanying capillary tubes and nozzles, as well as the symmetrical arrangement of the exhaust tubings so that the general flow of gases from both input to output is extremely uniform and symmetrical.

The above apparatus satisfied every necessary condition to enable mass production of epitaxial crystals yielding extremely substantial increased production quantities, while at the same time yielding crystals having extremely uniform characteristics.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appending claims.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows:

1. A heater element for use in apparatus employed in the manufacture of epitaxial crystals, said heater element comprising first, second and third individual metallic heater sections, each of said heater sections having a spiral configuration being symmetrical about a single point; a first surface of each of said first, second and third sections all lying within a plane; the inner ends of said sections being electrically connected; the outer ends of said sections having terminals for connection to a suitable three phase power source; the sides of adjacent heater sections being separated from one another by a constant predetermined distance to form three elongated spaces; each of said elongated spaces having a spiral configuration formed by connecting one-third of a circumference of a circle which portions are successively drawn about an associated center point successively selected from three vertices of an equilateral triangle formed at the center of a heating element and having its center of gravity at said single point; the width of each heater section being constant over its entire length and being equal to the length of a side of said equilateral triangle; the width of said elongated spaces being equal and being substantially less than the width of said heater sections; a substantially circular-shaped housing enclosing said heater element; means for introducing gaseous mixtures, employed in the epitaxial manufacturing process, into said housing in a constant uniform manner over the region adjacent the planar surface of said heater element.

2. The heater element of claim 1 wherein the first surface of each heater element is a substantially flat surface for supporting said crystal substrates; and a substantially convex opposing surface being provided to form a substantially convex cross-section to provide uniform heat over the entire surface area of said heater element.

3. Apparatus for the manufacture of epitaxial crystals comprising a metallic housing defining a reaction chamber therein; said housing being substantially circular; one half of said housing having a plurality of annular manifolds being concentric to one another; a plurality of inlet tubes exterior to said housing connected to an associated manifold; each of said manifolds having a plurality of openings symmetrically arranged about the associated manifold communicating between the manifold and the reaction chamber; the remaining half of said housing being provided with outlet means for exhausting gases from said reaction chamber; a substantially circular heating element positioned within said reaction chamber for providing a uniform temperature level across the entire chamber for heating crystal substrates supported by said heating element.

4. The apparatus of claim 3 wherein each manifold

opening is provided with a capillary tube and a nozzle for symmetrically and uniformly guiding gaseous mixtures into said reaction chamber.

5. The apparatus of claim 3 wherein said outlet means is comprised of a plurality of exhaust tubes symmetrically arranged about said remaining housing portion for guiding gaseous mixtures out of said reaction chamber to maintain a continuous even flow of gases within said reaction chamber; a gas trap being coupled between said exhaust tubes and the exterior of said housing.

6. Apparatus for the manufacture of epitaxial crystals comprising a metallic housing defining a reaction chamber therein; said housing being substantially circular; the upper half of said housing having a plurality of annular manifolds being concentric to one another; a plurality of inlet tubes exterior to said housing connected to an associated manifold; each of said manifolds having a plurality of openings symmetrically arranged about the associated manifold communicating between the manifold and the reaction chamber; a heater element positioned in said reaction chamber for use in uniformly heating crystal substrates used in the manufacture of epitaxial crystals, said heater element comprising first, second and third individual heater sections, each of said heater sections having a spiral configuration being symmetrical about a single point; the cross-section of each of said spiral sections continuously decreasing from the center outward to provide uniform heat across the chamber; said first, second and third sections all lying substantially within a plane, the inner ends of said sections being electrically connected; the outer ends of said sections having terminals for connection to a suitable three phase power source.

7. The device of claim 1 wherein the three-phase power source is a delta-connected system; each of said terminals being respectively connected to one phase of said delta-connected three-phase system.

8. The device of claim 1 wherein the three-phase power source is a Y-connected three-phase system; the center point of the Y-connected three-phase system being electrically connected to the center of said heating element and being electrically grounded; said terminals each being respectively connected to one of the phases of said Y-connected three-phase system.

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