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[54] CHEMICAL DEPOSITION APPARATUS

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[51] **Int. Cl.** **C23c 13/08**

[58] **Field of Search** 118/48–49.5; 117/107.1; 269/55, 57

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[57] **ABSTRACT**

A vertical flow-type deposition apparatus, typically for growing semiconductor layers, including epitaxial layers, upon a large plurality of substrates at one time. These are carried, vertically disposed, upon the outside of a rotatable barrellike susceptor, while an induction heating coil is within the susceptor. Vapors or gases for processing are admitted at the bottom of a water-cooled enclosure and are exhausted at the top. The coil is separated from the processing volume by a refractory shield.

5 Claims, 2 Drawing Figures

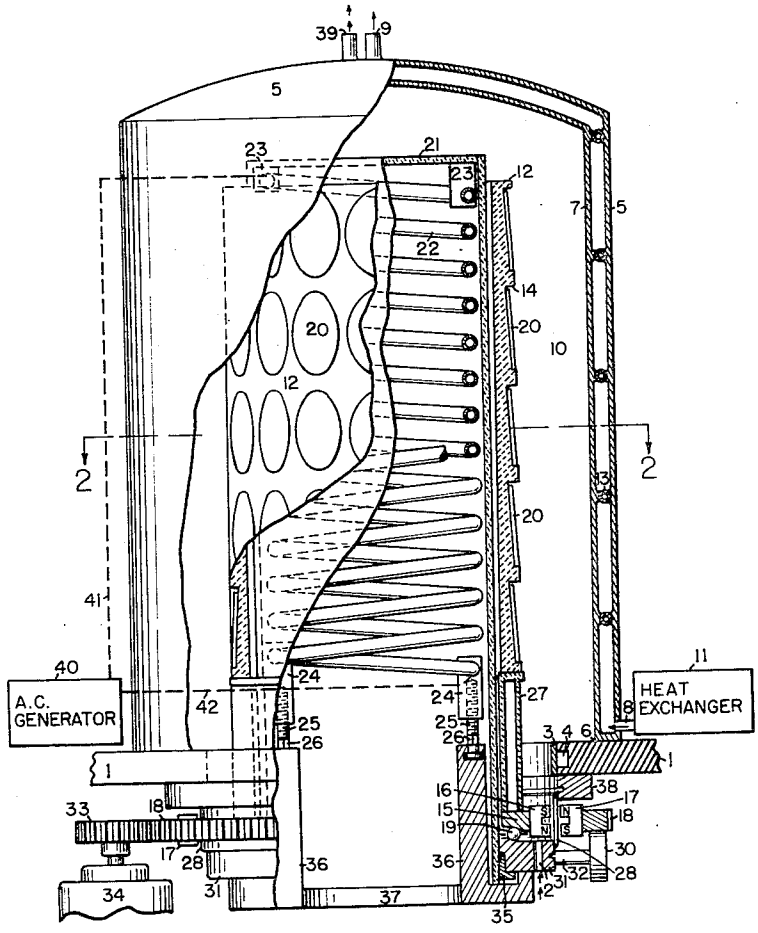
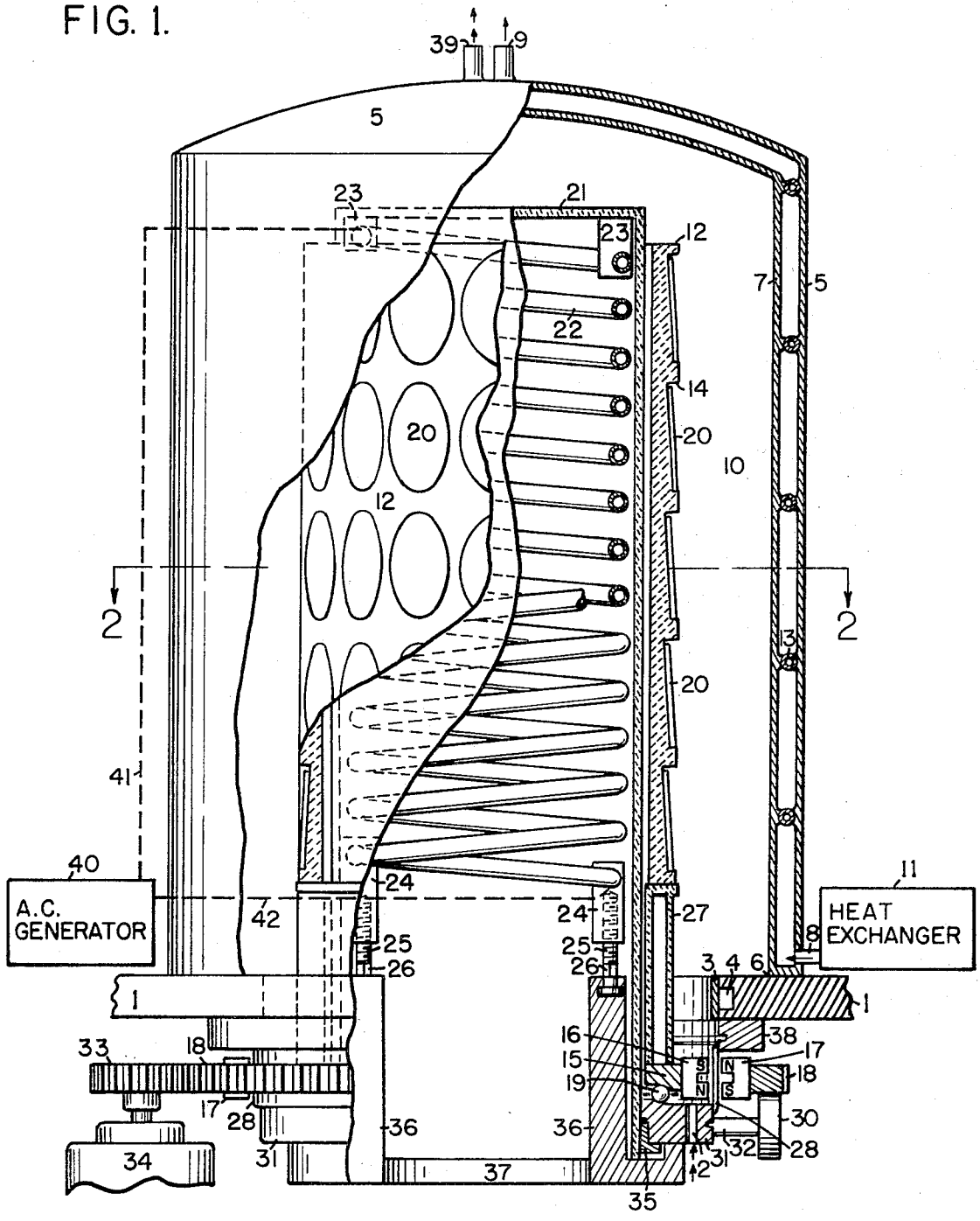


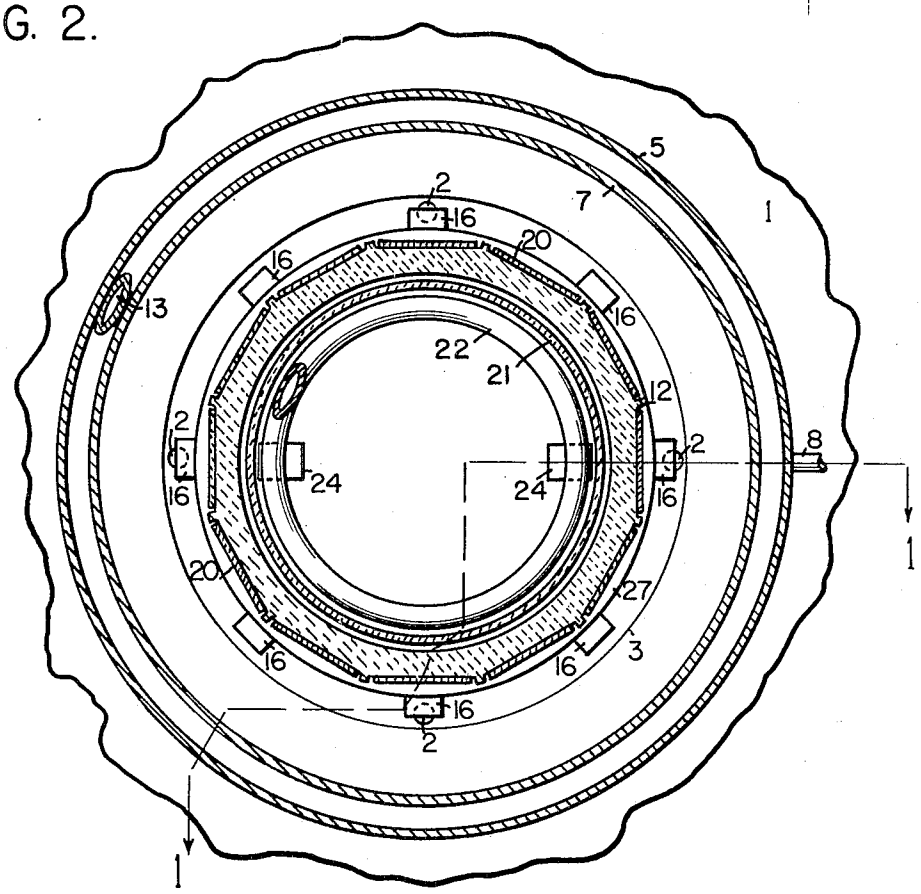
FIG. 1.



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FIG. 2.



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CHEMICAL DEPOSITION APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to high-temperature processing apparatus used for preparing thin films of semiconductor or dielectric materials useful in fabricating semiconductor devices.

The conventional reactor for semiconductor processing is of horizontal construction, with the substrates or wafers to be processed resting upon a dishlike susceptor. An induction coil for heating surrounds the susceptor *outside* of a horizontally disposed vacuumtight tube of quartz.

Pancake-type coils under a rotating horizontal susceptor within a bell jar have been used in early so-called vertical reactors. Some vertical reactors have been known, but these have employed a fully external heating coil of relatively large size. Such a coil must be removed each time the reactor is reloaded. This imposes certain difficulties in maintaining batch-to-batch uniformity of product, since it is difficult to reposition the coil in exactly the same position with exactly the same turn-to-turn spacing for each batch.

Additionally, early vertical apparatus included an open-to-the-atmosphere exhaust aperture at the top of the bell jar. This precluded establishing a vacuum in the workspace and prevented a concomitant increase in the precision of processing.

BRIEF SUMMARY OF THE INVENTION

The invention is concerned with a processing reactor employing a vertically disposed cylindrical susceptor with a helical heating coil internal to the susceptor. Normally, the susceptor is rotated; by an external mechanical drive. This is preferably coupled to the susceptor by a mechanical-magnetic drive, eliminating the need for a rotating vacuum seal.

Additionally, the coil is sealed from processing gases by a refractory quartz liner, or coil-enclosing cylinder. This construction also reduces the volume of such gases required to fill the reaction chamber. Thus, the composition of a gas can be changed more rapidly than in other reactors holding the same number of wafers.

A vertically upward gas flow pattern fosters uniformity of processing.

A cooled metal enclosure may be adjusted in temperature to avoid condensation of reactant products upon the inner walls thereof. Moreover, this surface is easily cleaned.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view of the apparatus, in broken section along lines 1—1 in FIG. 2 to best illustrate the structure.

FIG. 2 is a plan view of the same, also in section, and along lines 2—2 in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, numeral 1 identifies a vacuum baseplate. It is suitably supported at a convenient height for working by known means not shown. Passing through the plate are plural means to selectively introduce gaseous reactants into the working volume, these being entrance apertures 2. In general these may vary in number and placement, but in exemplary apparatus four apertures uniformly spaced (at 90°) radially relatively central to the annular working volume have been satisfactory.

It has been found desirable to water-cool the baseplate. This has been accomplished by an annular path 4 within the plate. The path has a radius approximately the same as the center of the working volume in order to cool where the most heat is generated. The path may be formed by turning a circular groove central of the thickness of the baseplate and then forcing in enclosing ring 3 to provide a watertight channel. Suitable inlet and outlet holes are provided to accommodate the flow of cooling medium, but these have not been shown for sake of clarity.

Cooled enclosure 5 is normally of cylindrical shape, with a closed domed top to withstand external atmospheric pressure at such times as a vacuum is within the enclosure. The lower surface 6 of the enclosure is machined flat so that a vacuum-tight joint can be made with baseplate 1 with the addition of known vacuum grease to aid the seal. An equivalent O-ring construction may also be used.

The enclosure is arranged for cooling by the provision of inner liner 7. A cooling fluid, typically water, is circulated within the space between the enclosure and the liner by a nominal pressure from pump means not shown. The flow is between inlet 8 at the bottom of the structure and outlet 9 at the top. It has been found desirable to form a spiral baffle 13 of tubing to occupy the space between the enclosure and the liner in a spiral having perhaps five convolutions. The tubing is welded in place. The cooling medium thus swirls upward around the cavity so formed, as desirable for uniform cooling.

Stainless steel is a suitable material for this structure. Aluminum is an alternate material. Typically, the interior of the liner is highly polished to allow easy cleaning of any reactants that might deposit thereon during the use of the apparatus, and to reflect the heat of processing.

It has been found that usual cold tap water may be used for the cooling fluid; however, the possibility of condensation of reactants upon the inside of the liner 7 is then present. When the temperature of this fluid is increased, to be somewhere between room temperature and the temperature within the operating workspace 10, this possibility is greatly reduced. An increase in temperature is accomplished by passing the cooling fluid through heat exchanger 11. In this known device the temperature of the fluid is regulated by thermostatically actuated valves which arrange an appropriate degree of recirculation of the fluid. The base cooling path 4 may be coupled into the exchanger cooling system, preferably at the cool (beginning) end thereof, or a separate flow of cool water may be provided. Suitable known hoses and fittings are employed for completing the recirculation circuit through inlet 8, outlet 9, and coupling-in the path 4 if desired, and these have not been shown.

Susceptor 12 is typically a right-cylindrical element having a length twice its diameter and is formed of graphite. The whole apparatus may be constructed in a wide variety of sizes and of some variation in shape and materials of construction, but a length of 10 inches, diameter of 8 inches, and a thickness of graphite of from ½ to 1 inch may be considered nominal. The shape of this element gives rise to the term "barrel reactor" for the whole apparatus. Equivalent shapes may also be used, such as a truncated conical section with limited conical slope to the outer surface.

The susceptor is normally machined and includes a large plurality of recesses or indentations 14. These carry the workpieces, substrates or semiconductor wafers 20, by the workpieces simply resting in the indentations, necessarily at a slight inward angle at the top.

Uniformity of processing is a mark of excellence of any reactor apparatus. This is found to be exemplary herein if the inward-leaning indentations have an angle with the vertical of the order of 2½°. This provides enough slant to retain the wafers in place despite rotation of the susceptor and prevents a reduction of deposit at the top of each wafer, particularly with certain reactants, such as silane (SiH_4). For other reactants, such as silicon tetrachloride ($SiCl_4$) or trichrorosilane ($SiHCl_3$), an angle to the vertical of the order of 7½° is allowable. Uniformity of processing has been repeatedly measured and is within a very few percent of absolute uniformity.

Susceptors are usually provided for variously sized wafers or substrates, as 1 inch, 1½inch, 2 inch, or larger diameters. A maximum capacity of 50 2-inch diameter wafers per susceptor in an exemplary model is typical. For greater capacity two susceptor-enclosure entities may be employed with a common processing control system.

The susceptor is arranged for rotation to enhance uniformity of processing. While this may be provided by a rotary

vacuumtight joint at the bottom of the apparatus, a magnetic drive has proven superior. Within the processing enclosure susceptor **20** stands upon refractory cylindrical support **27**, say of quartz, which support thermally insulates the mechanism below from the often red-hot heat of the susceptor. Support **27**, in turn, is supported upon driving ring **15**, which is also the upper race of a ball bearing and retainer structure **19** and so this ring is made of hardened steel.

Equally spaced around driven ring **15** are a plurality of driven magnets **16**, such as eight. These are of the known high-flux permanent magnet type and are in the shape of a miniature horseshoe, with opposite poles at opposite extremities facing outward around the ring. These face an equivalent structure of driving magnets **17**, facing inward, and driving ring **18**, through stationary intermagnet membrane **28**. The latter is fastened by welding to the inner cylindrical surface of baseplate ring **38**, which in turn is welded to baseplate **1**, and to the outer surface of stationary lower race **31**. Membrane **28** is preferably formed of stainless steel. It is necessary that the membrane be vacuum tight and also to withstand atmospheric-to-vacuum pressure structurally.

The outer periphery of driving ring **18** is supplied with gear teeth, making it in effect a ring gear, as well as means for carrying drive magnets **17** on its inner surface. Ring **18** is supported by plural rollers **30**, say three, which are attached to stationary lower race **31** by shafts **32**. This race also supports the whole susceptor rotating structure through balls **19** and also carries plural entrance apertures **2**, of which four is a typical number. Selected gases and/or vapors are introduced into working space **10** of the apparatus for processing purposes through apertures **2**.

The gear on ring **18** is driven by pinion **33**, which is attached to motor **34**. With the speed reduction thus obtained the susceptor is rotated at selected speeds within the range of from 2 to 10 revolutions per minute (r.p.m.). Magnets **16** and **17** are oriented so that a north pole of one is opposite a south pole of the magnet facing it. Thus, there is strong magnetic attraction and the inner rotating structure rotates at the same speed as the outer one. Typically, the motor is supported from plate **1**, but this and other nonvital supports have been omitted from the drawings for sake of clarity.

Refractory shield **21** is held stationary and vacuumtight by angle sealer **35**, which fits between it and stationary lower race **31**. Coil support **36** has a lower ring **37**, which is attached to the lower surface of lower race **31**. The upper extent of support **36** holds adjusting screws **25**, about which more is stated later herein. Supports **36** need only be columns under each adjusting screw.

A distinct advantage of the structure of this apparatus is the reduction of working volume **10** to that required for processing alone. This is accomplished by the inclusion of refractory shield **21**. This shield is typically formed of quartz, of cylindrical shape and with an enclosing top. It fits inside of susceptor **12** and is fastened in place by angle sealer **35**. As has been mentioned, its presence allows the composition of a gas to be changed more rapidly in processing than in other reactors holding the same number of wafers.

Within the shield, heating coil **22** is supported by upper clamps **23**, which may be fastened to the shield or otherwise supported. At the bottom, coil **22** is supported by lower adjustable clamps **24**, which, in turn, are supported by adjusting screws **25**. These screws are provided with round heads that are blind-anchored in corresponding round recesses in supports **36**. Square or hexagonal sections **26** are formed directly above the supports to allow rotation of the screws with a wrench or equivalent tool. The screws enter threaded holes within lower clamps **24**, and when turned force the clamps upward or downward, depending upon the direction of rotation of the screws. All clamps **23** and **24** are preferably of electrical insulating material, or are otherwise arranged so that turns of the coil **22** will not be shorted.

This means of adjusting the position of helical coil **22** and the pitch between any or all of its convolutions allows maximization of the heating effect upon wafers **20**. Typically, this is maximized for uniformity. By initially slightly deforming coil **22** axially, from normal uniformity between spacing of the turns, factors which act against uniform heating of the work can be compensated for.

Coil **22** may be merely a resistance element and heat for processing the work obtained from I^2R loss of electric current caused to flow through it. However, it is preferable that the coil induce heating by causing current to flow in the electrically resistive susceptor **12** and the I^2R loss thereof cause the heating. This is accomplished by supplying an alternating current of high frequency to coil **22**.

Accordingly, coil **22** is normally constructed of high-conductivity material, such as copper, in tubular form. This form is as shown in the upper right sectioned part thereof in FIG. **1** and by the ellipse section in FIG. **2**. Preferably a cooling fluid, typically water, is passed through the tubing of the coil. Suitable hydraulic connections are attached to each end thereof, but these have not been shown, and merely convey the fluid in one end of the coil and out the other by insulating hose means that will not electrically short the coil.

It has been found that an alternating current having a frequency as low as 10,000 Hertz may be used. This may be provided by AC generator **40** of the mechanically rotating type, such as is manufactured by the Tocco Corporation. A power output of 50 kilowatts is nominal. Because of this relatively low alternating current frequency the generator may be located as far as 200 feet from the apparatus of this invention without appreciable electrical loss. The output of the generator is connected to the extremities of coil **22**, as is indicated by dotted connections **41** and **42**.

Exit aperture **39** communicates with the top of the operating workspace **10**, to allow exhausting vapor or gas reactants employed in various processing steps that have entered the workspace through apertures **2**. One exit aperture, essentially centered with respect to the workspace, has been found sufficient. Typically, aperture **39** is connected to a vacuum pump, not shown, to rapidly exhaust volume **10** and to avoid contamination thereof by any backflow of air. It will be understood that the number and the placement of entrance and exit apertures has an influence on the uniformity of processing and that this aspect has been maximized herein.

The various processes of epitaxial growth, cleaning, etching and doping possible in an apparatus of this type are known. As examples, epitaxial growth of silicon or germanium layers at precisely controlled rates, as by the reduction of silicon tetrachloride with hydrogen or the pyrolysis of silicon hydride, are possible. So also, hydrogen chloride etching, nitriding, oxidizing and carbiding, also surface catalyzed pyrolytic deposition of metals or dielectric compounds.

In the matter of doping, P-type impurity concentrations can be controlled over the range from 10^{15} to 10^{20} atoms per cubic centimeter, and N-type impurity concentrations from 10^{15} to 10^{19} atoms per cubic centimeter.

The structure of the apparatus of this invention and the polished and highly reflecting inner surface of inner liner **7** combine to minimize the requirement for heat exchanger **11**. Thus, successful production processing may be accomplished without it.

We claim:

1. A chemical deposition apparatus comprising;

a. an upstanding dual-walled enclosure (**5**,**7**),

b. a baffle (**13**) between the dual walls of said enclosure to direct cooling fluid circuitously upward between said walls,

c. a single essentially cylindrical susceptor (**12**) having a vertically disposed axis, and carrying a large plurality of substrates (**20**) to be processed, essentially vertically disposed upon the exterior of said susceptor,

d. annular magnetic means (**15**, **16**) revolvably carrying said susceptor and disposed within the volume (**10**) of said enclosure (**5**,**7**),

e. rotatable ring means (18) carrying plural circumferentially spaced magnets (17) disposed adjacent to and in magnetic relation to said magnetic means, outside of the volume of said enclosure,

f. plural vertical inlet apertures (2) spaced one from the other only at the bottom of said enclosure, said apertures being relatively concentric with said cylindrical susceptor, and

g. a single exit aperture at the top of said enclosure relatively concentric with said cylindrical susceptor, whereby gaseous reactants admitted at said plural inlet apertures flow upwardly past each of the rotating substrates.

2. The apparatus of claim 1, which additionally includes;

a. a refractory cylindrical support (27) interposed between said magnetic means (15) and said susceptor (12), to support said susceptor atop said magnetic means.

3. The apparatus of claim 1, in which;

a. said susceptor has a large plurality of recesses (14) each inclined inwardly toward the top thereof approximately 2½° for carrying said substrates (20) upon said susceptor.

4. The apparatus of claim 1, which additionally includes;

a. a heat exchanger (11) connected to said dual-walled enclosure (5,7) to maintain the temperature of said cooling fluid at a selected value suited to inhibit deposition of reactants upon the inner wall (7) of said dual-walled container.

5. The apparatus of claim 1, which additionally includes;

a. a path (4) for cooling fluid within said baseplate (1) adjacent to said inlet apertures.

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