

June 4, 1968

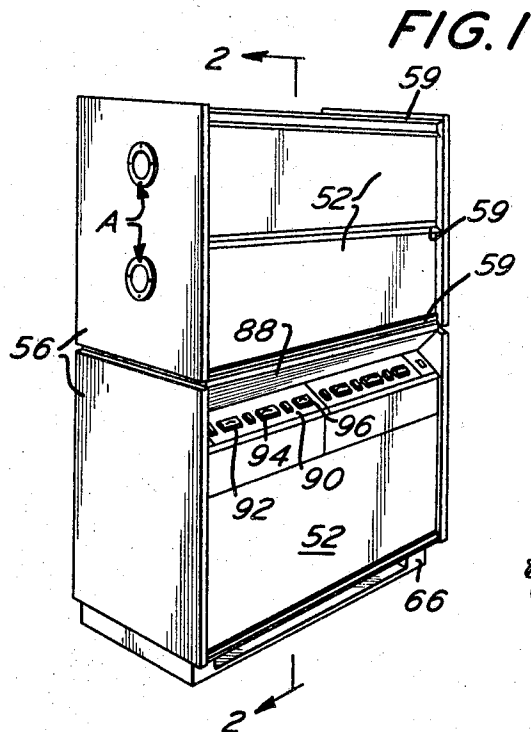
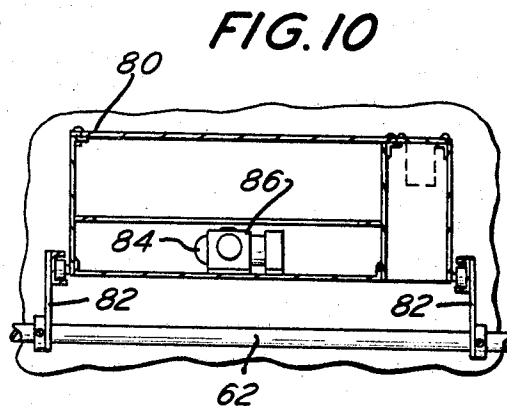
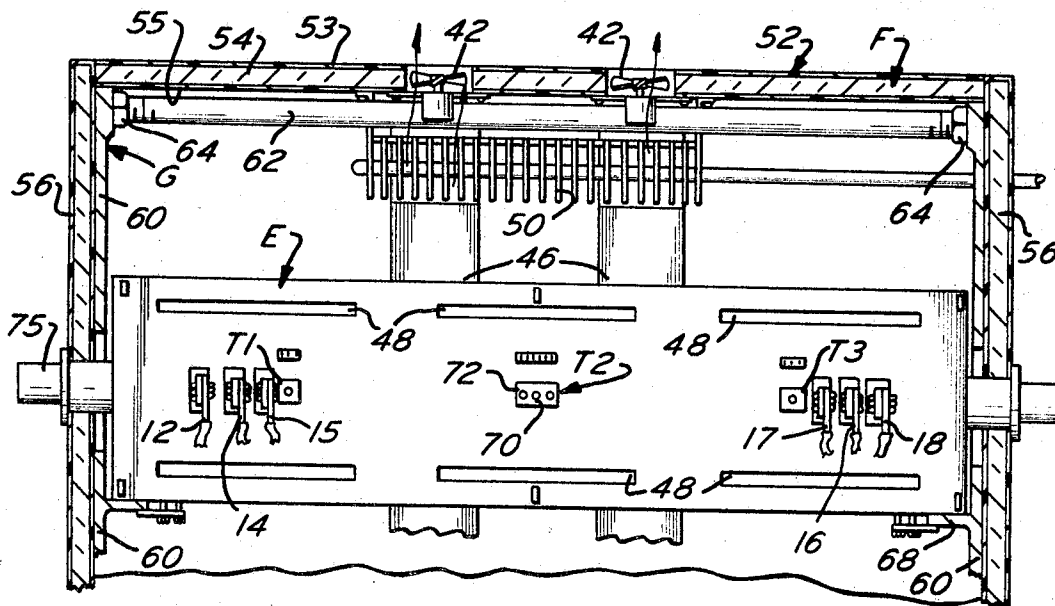
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3,387,078

DIFFUSION FURNACE WITH FLAT RECOVERY

Filed June 15, 1966

6 Sheets-Sheet 1



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6 Sheets-Sheet 2

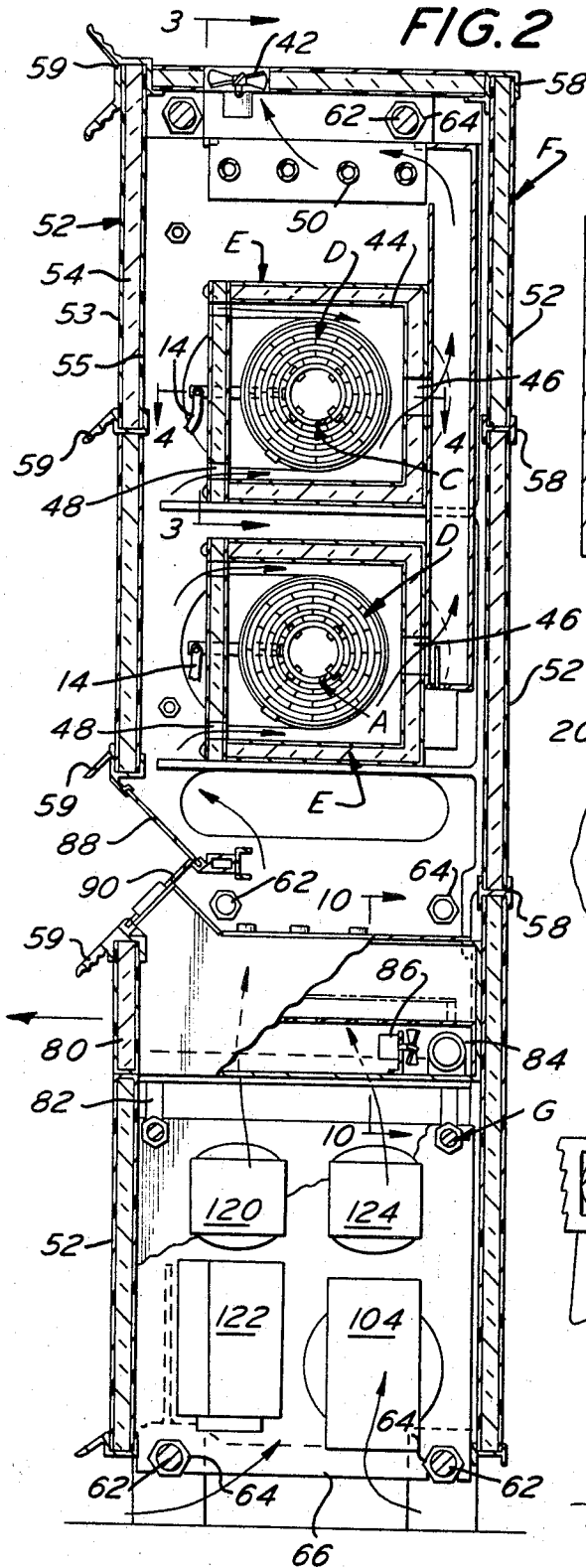
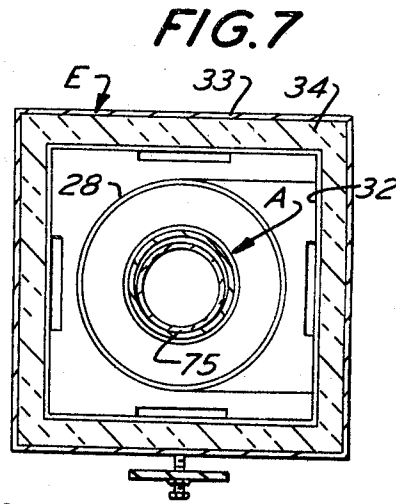
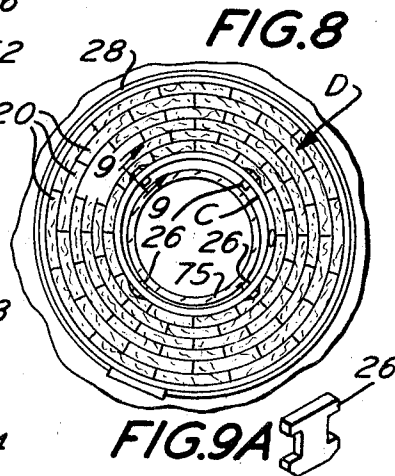
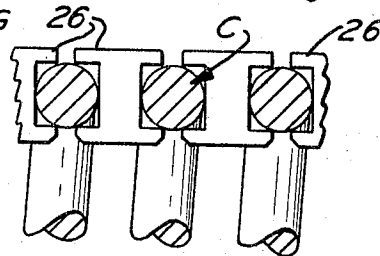


FIG. 9

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DIFFUSION FURNACE WITH FLAT RECOVERY

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6 Sheets-Sheet 3

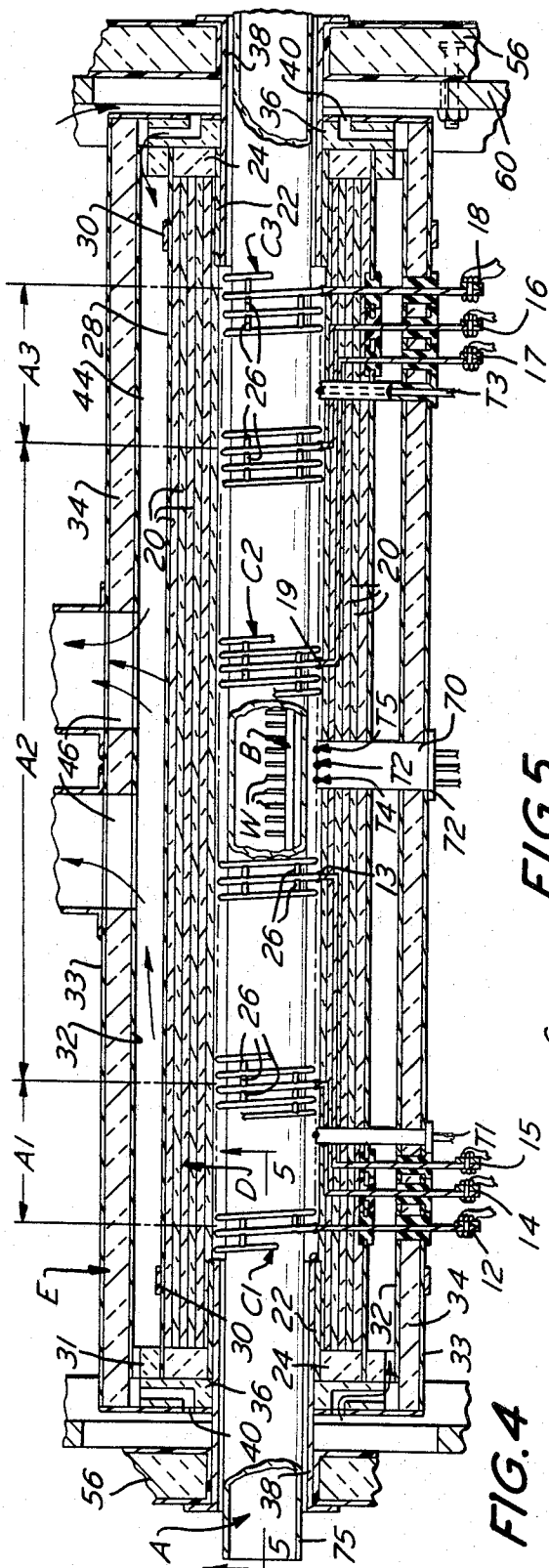


FIG. 4

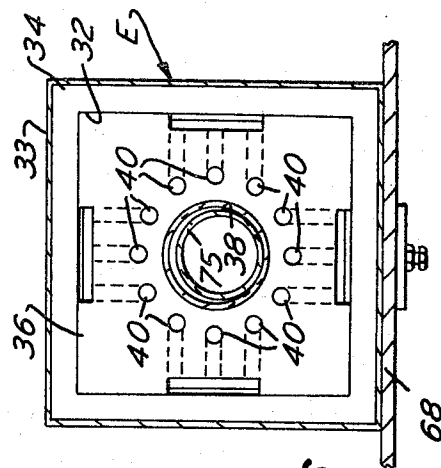


FIG. 6

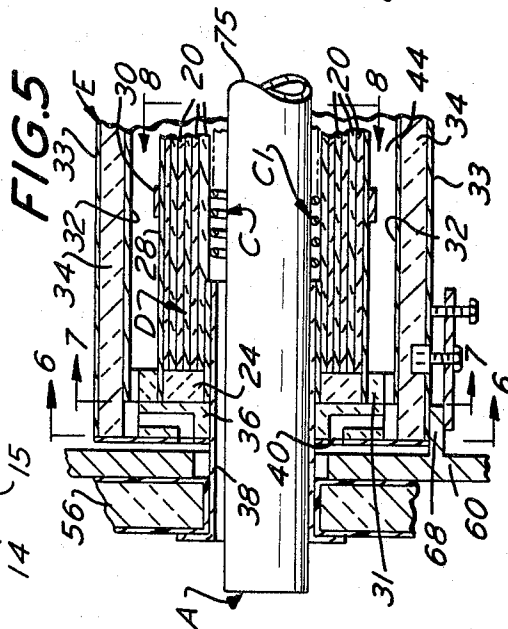


FIG. 5

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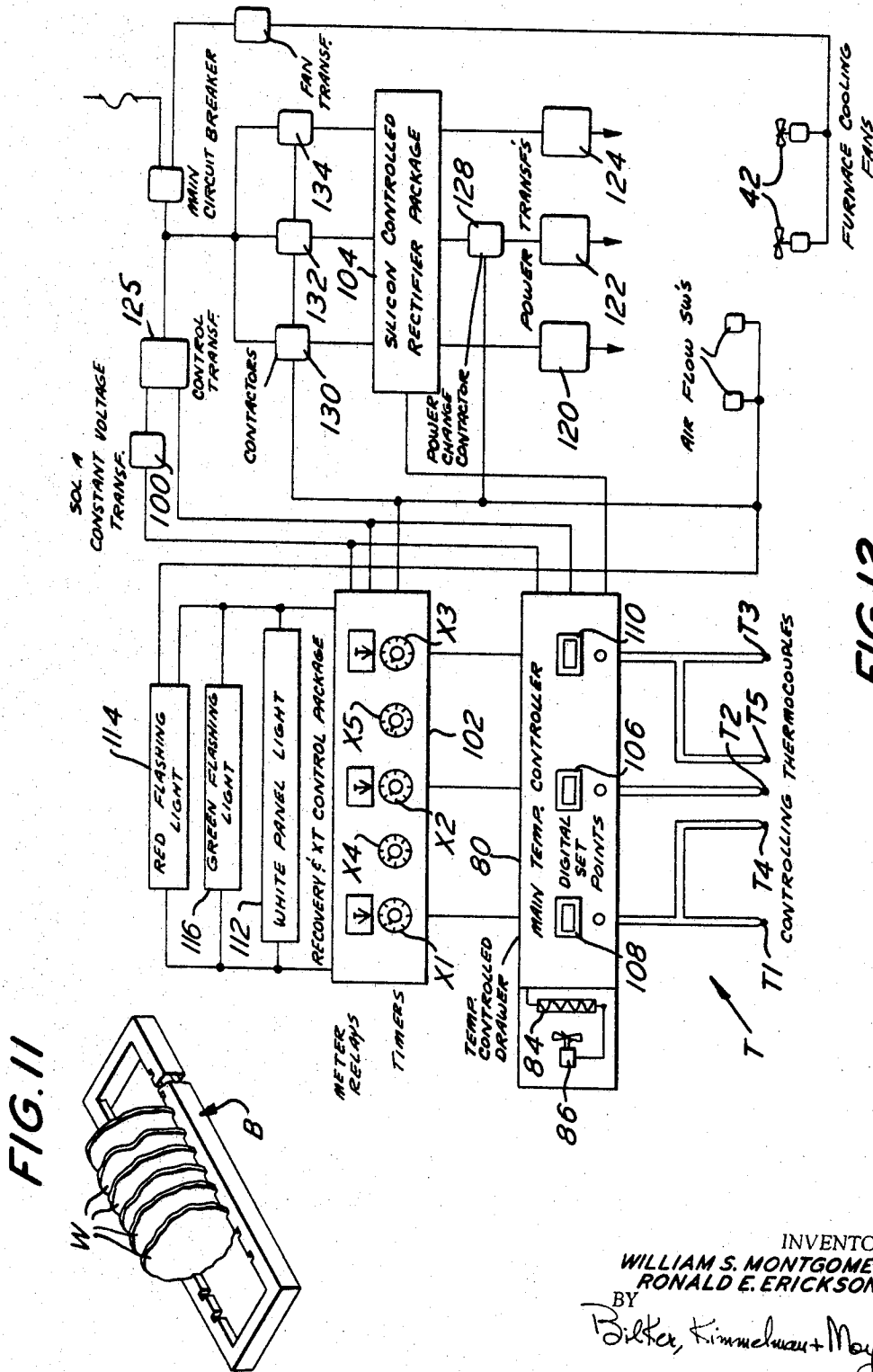
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6 Sheets-Sheet 4



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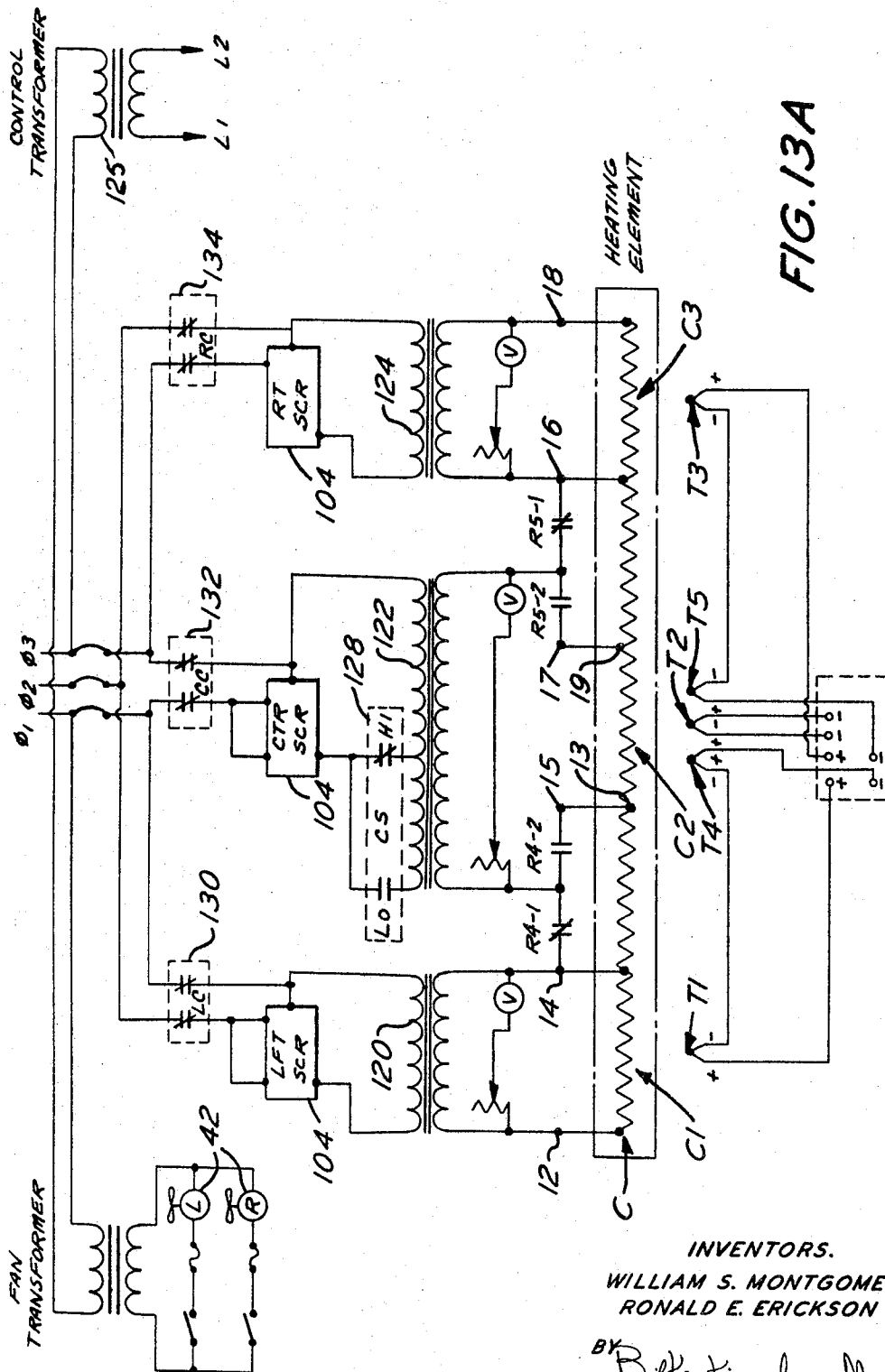


FIG. 13A

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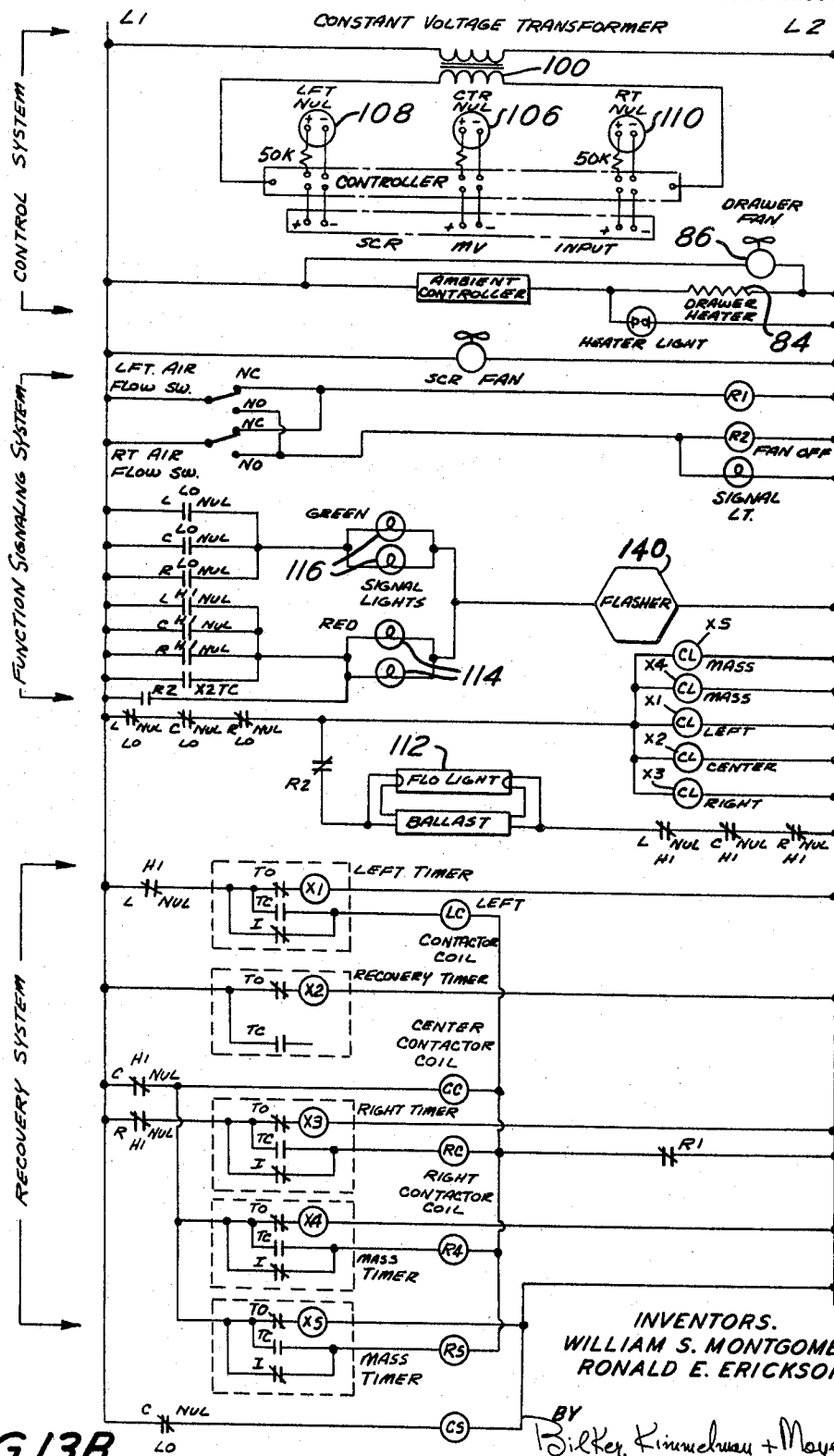
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DIFFUSION FURNACE WITH FLAT RECOVERY

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6 Sheets-Sheet 6



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FIG. 13B

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3,387,078

DIFFUSION FURNACE WITH FLAT RECOVERY
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Filed June 15, 1966, Ser. No. 557,786

22 Claims. (Cl. 13—24)

ABSTRACT OF THE DISCLOSURE

A diffusion furnace with rapid flat recovery profile and operative at a uniform elevated temperature across the treatment zone comprising a plurality of independently controlled heating zones with means to cut-off the heat to the end zones for predetermined periods of time after the material to be treated enters the furnace. Insulation selected for incorporation about the heating zones operate at minimum K-factor for the anticipated mean temperature of operation and in the flat portion of the temperature versus K curve so as to provide low mass and thereby avoid overshooting.

This invention relates to a precision furnace, and more particularly relates to a diffusion furnace for use by the semiconductor industry in connection with the doping of semiconductor wafers with solid state impurities.

In the fabrication of semiconductor and microcircuit wafers, it is the practice in the industry to heat up a large number of semiconductor slices within a tubular furnace chamber while exposing the slices to an environment of a particular doping impurity. Such a process is essentially a batch-type operation in which the slices or wafers are loaded upon a quartz carrier, called a boat, and inserted within a horizontally-extending high temperature resistant tube having a helically wound heating element surrounding it. The boat, with its cargo of semiconductor slices is pushed into the hot zone of the furnace from one end while the dopant may be introduced in the form of a vapor from the other end or vaporized within the furnace itself. The dopant may also be painted on or deposited upon the wafers prior to the diffusion process. It is, of course, apparent that with any of the modes of doping the rate of diffusion or the thickness of the diffused layer of the dopant impurity upon the wafers depends not only upon the concentration of the impurity and the time during which the heated wafers are exposed to the doping environment but also upon the temperature at which the exposure is accomplished.

Over the years, the techniques for controlling the concentration of the solid-state vapor within the furnace chamber have been greatly refined so that the variable of maintaining the gaseous impurity concentration can be achieved within rather precise limits. The variable of time has always been easily controlled where the exposure period is of considerable extent in contradistinction to split seconds. However, the need of precise temperature control becomes increasingly sensitive where the demands of ever-growing production requirements call for greater rate, greater economy, greater speed, less time. Whereas a usual diffusion cycle ran perhaps twenty-four hours during early phases of this semiconductor industry, today the maximum total diffusion exposure may be less than twenty-four minutes. As a consequence, the control of the temperature variable has now become quite critical, and the limits of temperature variation must be maintained within a small fractional portion of a degree.

For example, a typical diffusion is conducted at 1300° C. A typical quartz boat upon which the semiconductor slices (50 to 100) are stacked may be 22 inches long.

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Hence, a flat temperature profile must be maintained across the entire zone of the furnace in which the diffusion is conducted or the slices at one portion of the boat will have a different thickness of dopant deposition than another.

Usually, the furnace is brought up to operating temperature and the dopant impurity introduced through one end of the furnace. The boat load of semiconductor slices is now inserted through the other end of the furnace, and obviously the furnace temperature will drop out of the control range as a result of the heat absorption by the cool mass of the boat. One of the most critical areas in the operation of a diffusion furnace is that of boat heat-up, sometimes referred to as recovery. This portion of the cycle becomes increasingly critical as the total time of deposition is reduced and drive-in operations become shorter. The important phase of boat heat-up is not the actual time taken by the boat to reach temperature, but rather the flatness of the temperature profile across the boat during recovery.

For example, in the heat-up of a 530-gram 22-inch long boat, the total time required for the boat to recover from room temperature and to reach the elevated temperature (1300° C.) may be approximately 15 minutes during which time the diffusion cycle is constantly going on. The total diffusion period may run 24 minutes, i.e., 9 minutes in excess of the 15-minute recovery period. Consequently, a variation in excess of $\frac{1}{10}$ of 1° C. across the boat could result in appreciable variations in diffusion layer thickness. Acting in direct opposition to uniformity of heat build-up across the boat is the effect of the inherent elongated geometry of the boat itself. That is, since there is a greater surface-to-mass ratio at the ends of an elongated object than there is at the center, such an object would heat up more rapidly at its ends where more surface is exposed. Furthermore, the thermodynamic properties of the boat combine with the kinematic system of moving the boat into the furnace from one end or the other. Thus, just inserting the boat into the furnace causes the forward end of the boat to be heated up more rapidly than the aft portion in addition to the fact that the recently opened end of the furnace must necessarily be cooler than the opposite closed end.

In addition, one must also consider the possible entire spectrum of boats which the various processors may utilize, i.e. from one which is 7 inches long and having a mass of 100 grams to one 22 inches long and having a 550 gram mass, as well as the infinite number of combinations therebetween. Lastly, also to be considered are all of the possible temperatures of operation to which the different customers may subject the various combinations of boat length and weight.

It is therefore an object of this invention to provide a diffusion furnace having a perfectly flat temperature profile across the entire hot zone.

Another object of this invention is to provide a diffusion furnace which will yield a precisely controlled flat temperature profile during heat build-up or boat recovery period.

Yet another object of this invention is to provide a diffusion furnace in which a higher rate of production of uniformly doped semiconductor wafers may be achieved.

Still another object of this invention is to provide a diffusion furnace in which a higher speed of temperature response is afforded.

A further object of this invention is to provide a diffusion furnace having a minimum mass of insulation so that

Yet still another object of this invention is to provide a diffusion furnace in which the temperature controls themselves are stabilized against temperature effects.

Still a further object of this invention is to provide a diffusion furnace in which all insulation components are adapted to operate at their optimum K factor.

Yet a further object of this invention is to provide a diffusion furnace which will operate with minimum drag upon outside air-conditioning facilities.

A still further object of this invention is to provide a diffusion furnace construction which lends readily to modular erection.

Other objects of this invention are to provide an improved device of the character described which is sturdy in construction, that is easily and economically produced, and which is highly efficient and effective in operation.

With the above and related objects in view, this invention consists of the details of construction and combination of parts as will be more fully understood from the following detailed description when read in conjunction with the following drawings in which:

FIGURE 1 is a front perspective view of a diffusion furnace embodying this invention.

FIGURE 2 is a sectional view taken along lines 2—2 of FIGURE 1.

FIGURE 3 is a sectional view taken along lines 3—3 of FIGURE 2.

FIGURE 4 is a sectional view taken along lines 4—4 of FIGURE 2.

FIGURE 5 is a sectional view taken along lines 5—5 of FIGURE 4.

FIGURE 6 is a sectional view taken along lines 6—6 of FIGURE 5.

FIGURE 7 is a sectional view taken along lines 7—7 of FIGURE 5.

FIGURE 8 is a sectional view taken along lines 8—8 of FIGURE 5.

FIGURE 9A is a perspective view of a ceramic spacer. In section taken generally along lines 9—9 of FIGURE 8.

FIGURE 9A is a perspective view of a ceramic spacer. FIGURE 10 is a sectional view taken along lines 10—10 of FIGURE 2.

FIGURE 11 is a perspective view of a boat supporting a plurality of semiconductor wafers preparatory to diffusion treatment within the furnace of the instant invention.

FIGURE 12 is a diagrammatic block representation of the control system of the instant invention.

FIGURE 13A is an electrical schematic diagram of the sensing and heating circuits.

FIGURE 13B is a schematic across-the-line wiring diagram of the control circuits.

Referring now in greater detail to the drawings in which similar reference characters refer to similar parts, the diffusion furnace of the instant invention comprises an elongated chamber A, including a central or hot zone A2 which is adapted to support a boat B carrying semiconductor slices during deposition, a first end zone A1 through which the boat is passed into the central zone, and a second end zone A3 in advance of the boat being treated and through which dopant impurities are introduced as a vapor. See FIGURE 4. A heating coil C is helically wound about the chamber A and includes tapped coil portions C1, C2 and C3 which correspond to the individually controlled zones A1, A2 and A3 respectively. A low mass insulation D surrounds the heating element C, and an intermediate insulated shell E is spaced thereabout and encapsulates the interior insulation D. Refer to FIGURES 2, 5, 6 and 7. Finally, the intermediate shell E is housed within an outer shell assembly F, all being supported upon a frame G which affords a modular construction for erecting the entire furnace or a plurality of them.

Referring now to FIGURE 4, the chamber A is in the form of an integral unit whose construction begins with the heating coil C which may be manufactured from Kanthal A-1 wire of #2 gauge. The wire is wound in the

form of a helix approximately 40 inches long, and the spiral has an inside diameter of 4 inches, for example. The center coil portion C2 is approximately 24 inches and is effective to accommodate a boat B having a length of up to 22 inches. Taps 12, 14, 16 and 18 are heli-arc welded to the coil element C to define the end coil portions C1 and C3 which are each 8 inches long. The end coil portions C1 and C3 are each rated at 1.8 kilowatts while the center portion C2 is rated at 5 kilowatts, the various coil zones being supplied by suitable electrical power packages as will be more fully developed hereinafter. Meanwhile it is deemed sufficient to mention at this point that each of the coil portions are actuated independently through separate timing systems empirically set up whereby a flat profile heat-up is provided in the central hot zone A2. An empirical system of recovery is possible with the furnace of the instant invention because of its extremely low mass.

The inner insulation D comprises strips of ceramic fiber insulation 20, such as Johns-Mansville "Cerafelt", 24-pound density. As shown in FIGURES 4 and 8, these insulation strips 20 are laid in a plurality of concentric layers about the coil C in the manner of a lath. The ends of the lath 20 overlie the ends of the coil C and are radially supported by sleeves 22 having end collars 24. See FIGURE 5. Low mass ceramic spacers 26, which are I-shaped in configuration as shown in FIGURE 9, are oriented in quadri-sected circumferential intervals between adjacent coils of the heating element C. The spaces 26 have rectilinear lateral recesses so that only point or line contact of the circular Kanthal wire is made. In this manner, the low mass spacers 26 positively maintain the heating element coil separation thus assuring a flat, repeatable profile. The employment of the unit spacers 26 also permits great flexibility in enabling the customer to change and modify the spacing easily and without appreciable tooling cost. That is, one can readily change to another size spacer should a special heat configuration be required of a particular furnace or should it be necessary to maintain a flat profile. The tiny I-shaped ceramic spacers 26 which are circumferentially-spaced about the circular cross section of the coil C in combination with the ceramic felt lath 20 produces a small fraction of the insulation mass required by the prior art molded or cast wet ceramic insulation shell which utilized interior rib construction to perform the spacing function. In this manner, the ceramic insulation lath 20 requires no dry-out time, and furnace stability is achieved simultaneously with operating temperature. The assembly of coil C, spacers 26 and lath 20 are encased in an aluminum sheath 28 which is secured thereabout by circumferential straps 30 to define an interchangeable chamber cartridge A permitting replacement as a unit. It should also be noted that the low K factor ceramic fiber insulation 20 is operated at its optimum K factor. That is, the present furnace cartridge A uses only 2 inches of insulation lath 20 so that the mean temperature of the material is held at that which its K factor is the lowest. As is well known thermodynamically, the value of K (conductivity constant) for insulation materials tends to increase with increase in temperature. The present invention contemplates the selection of the insulation material which operates at minimum K in the flat portion of the K versus temperature curve for the particular mean temperature of operation.

Referring to FIGURES 4, 5 and 6, the intermediate shell E is a 52-inch long box which is square in cross-section and air-spaced about the cartridge sheath 28. The sides of the box are made of a lightweight sandwich in which aluminum sheet metal skins 32 and 33 are laminated about a layer 34 of foamed polyurethane, for example. End caps 36 at each end of the box E have a central aperture 38 and a plurality of ports 40 cored in circumferentially-spaced disposition thereabout and radially extending through the cap thickness. As may be seen from FIGURE 2, air is drawn by circulating fans 42 through

slits 48 in the front wall of the intermediate shell. The slits 48 may be varied in size to control the surface temperature of the cartridge sheath 28 and thus the operating temperature of the ceramic insulation lath 20. In order to maintain a cool surface temperature on the ends of the furnace, air is drawn by circulating fans 42 through ports 40 into the annular space 44 between the cartridge A and intermediate shell E and thereafter out through louvers 46 in the latter. The square intermediate shell E is the principal heat dissipating area for the system. The heat removed by the fans 42 is then ducted up along the back inner wall of the outer shell F. Optionally, the air may then be ducted out of the chamber and exhausted into the room or ducted through a finned type water cooler 50 before being discharged in order to eliminate any load on plant air-conditioning systems.

Referring to FIGURES 2 and 3, the outer shell assembly F is constructed of molded glass fiber panels 52 having a polyurethane insulating core 54, the core 54 being sandwiched between fiberglass laminates 53 and 55. End plates 56 of identical sandwich construction complete the shell F. The edges of the panels 52 are trimmed with aluminum extrusions 58 to provide reinforcement for the edges of the panels to facilitate assembly to each other and to the frame G, and for decorative purposes. The front panels 52 have special aluminum extrusion channels 59 to permit their removal for gaining access to the furnace and power equipment.

The frame G comprises a modular erector type system utilizing end castings 60 which are detachably secured together by threaded tie rods 62 and tightened with nuts 64. Base 66 supports the entire furnace and ribs 68 integrally extending interiorly from the end castings 60 detachably support the box-like intermediate shell or shells E with their cartridges A. A unique feature of the furnace construction is its capacity to be rebuilt or changed in the field. The modular construction makes possible the erection of a double stack chamber A, as shown in FIGURES 1 and 2, from a single stack arrangement, or to further convert into a triple stack system, not shown. The tie rods 62 also enable furnaces to be erected end-to-end with minimum difficulty.

Referring now to the schematic block diagram of FIGURE 12, the control system T is based upon a differential thermocouple arrangement or master-slave approach in which the temperature gradient between the center zone A2 and the respective end zones A1 and A3 are being continuously measured. Three thermocouples T2, T4 and T5 are located immediately adjacent one another directly in the middle of the center zone A2. An end zone thermocouple T1 is mounted in the left-hand end zone A1, and is connected in series bucking arrangement with thermocouple T4. A second end zone thermocouple T3 is mounted in the right-hand end zone A3 and is coupled in opposition to the center zone thermocouple T5. As shown in FIGURE 4, the three center zone thermocouples T2, T4 and T5 may be encased together within a vial 70 or so placed that they all see the same temperature whereas the end zone thermocouples T1 and T3 are each individually encapsulated. However, all of the control thermocouples pass through the intermediate shell E and thence to a predetermined depth within the chamber A after piercing the cartridge insulation D. The depth of immersion of the various thermocouples is oriented by a locking collar 72 on the exterior of the intermediate shell E. The collars 72 prevent the sensitive thermocouple tips from accidentally abutting against quartz diffusion tube 75 which sits within the chamber A and extends from one end to the other for supporting the boat B.

Referring back to FIGURE 12 and also to FIGURE 13A, the center zone section of the temperature controller T utilizes a Zener diode constant voltage reference source 100. The output of the center zone thermocouple T2 is matched against the reference constant voltage 100 through a differential amplifier 102 which proportionally

increases or decreases power to the furnace through a silicon controlled rectifier unit 104 until the difference between the reference source and the output of thermocouple T2 is zero. The center zone controller is equipped with proportional band and automatic reset. The controlling temperature is set by a four digit digital set point unit 106, which is included with the differential amplifier and silicon control rectifier package supplied by Minneapolis-Honeywell. In the case of the end zones A1 and A3, the differential amplifier 102, as shown in FIGURE 12, controls the difference between the end and the center reference—i.e., the output of T₁ with respect to T₄ or T₃ to T₅ so that if the temperature in the center zone A2 changes the end zones A1 and A3 will follow. Each end zone utilizes a four digit digital set point unit 108 and 110. The low mass of the insulation D enables the end zones A1 and A3 to operate with a proportional band of 1° C. and proportioning control permits the user to set the required differential between the center and end zone with the digital set points in 1/10 of 1° C. increments. Such differential measurement and control helps secure a flat profile in the center zone A2.

The obtaining of the flat temperature profile across the central zone A2 during boat recovery is accomplished by a series of timers whose operational sequence is determined empirically. That is, a timer X1 is coupled within the left-hand heating coil circuit C1 and is adapted to delay return to temperature of the proximal end zone A1. Timer X3 is coupled through the right-hand heating coil C3 and is adapted to delay return to temperature of the distal end zone A3. The purpose for the cutting off of power to the end zones A1 and A3 for a predetermined length of time after the "cool" boat B has been pushed into the furnace already at the flat profiled temperature is to prevent the far ends of the boat from overshooting. The control thermocouples T1 to T5 are each located outside of the diffusion tube 75 and return to control temperature in approximately half the time it takes the boat to come up to temperature.

For example, the forward end of the boat B which enters the furnace first will initially be cool and will therefore cause the distal end zone thermocouples T3-T5 to call for more heat as well as the central control thermocouple T2. As a consequence, the forward end of the boat will over-shoot the control point by a considerable amount and take appreciable time to return to stability. The aft end of the boat will cause a similar over-shooting to occur at that end as a result of the same general condition in zone A1 although to a lesser extent.

The overshooting of the forward and aft ends of the boat B is caused primarily by the fact that the end zones A1 and A3 will have returned to temperature and supply heat to the furnace chamber A2 itself so as to hold the furnace chamber essentially at a fixed temperature. However, at the ends of the boat, there is less mass to soak up this supplied heat. Therefore, the ends of the boat will heat up faster than the center of the boat. That is, where a relatively small elongated object is placed within a relatively large chamber at an elevated control temperature, the object will have little effect upon the environmental temperature conditions of the chamber because of the large amount of heat stored in the chamber. However, because of the lower mass of the elongated article at its ends, the ends of the object will necessarily heat up more rapidly than the center.

Coupled with the thermodynamic situation set forth above, is the fact that the boat B sits in the center zone A2 directly above the control thermocouple T2. Accordingly, the center zone control couple T2 is required to call for additional heat—i.e., to heat up the boat which was cool immediately prior to insertion. However, this additional heat is also subjected upon the ends of the boat. Therefore, in addition to the natural tendency of a boat to heat up faster at the ends, there is superimposed an equal amount of additional heat being supplied to both

the center and ends simultaneously so as to aggravate further the overshoot conditions on the ends of the boat.

Accordingly, the timer X1 is empirically set to cut off the supply of power to the left heating coil C1, end zone A1, for a predetermined period after the boat has been inserted. Correspondingly, timer X3 is likewise set to an empirically determined period for delaying the return of power to the right hand coil C3, and zone A3.

Since there is a wide range of boat length and weight combinations which may be employed by various customers, the diffusion furnace must be sufficiently flexible to accommodate the whole spectrum of short and long boats. That is, one must consider the need to adjust the length of the center zone A2 so that the relatively shorter boats will not be subjected to undue heat at the ends. A third timer X4 performs a switching function from terminal 14 to terminal 15 which is electrically coupled to center tap 15 at the medial portion of coil C2. See FIGURES 4 and 13. A fourth timer X5 performs a shunting of the coil C2 at the other end by switching terminal 16 to terminal 17 which is coupled with center tap 19. Thus, with shorter boats, it may be desirable to set timers X1 and X4 for the same period while timers X3 and X5 could be set to time out with each other. Thus, the timers X4 and X5 could be set empirically for short boats in the same manner as previously stated so that the left hand end zone would extend from tap 12 to tap 13 and the right hand end zone would extend from tap 19 to tap 18 for accommodating recovery of short boats.

In addition, it may be desirable under certain conditions to drive more heat into just the center portion of a long boat in order to compensate for the greater surface to mass ratio at its ends. Under such circumstances timer X4 may be set for a shorter period than X1 and timer X5 for a shorter period than X3. Accordingly, the latter empirically derived setting would provide a greater heat concentration from the medial portion of the central zone A2 during boat recovery. The permissible variations in time settings of the four timers X1, X3, X4 and X5 enables all of the wafers to be exposed to a constant temperature during recovery and prevents the wafers at the ends of the boats from being subjected to a higher temperature for a longer period of time than those in the center. This empirical system can be set either by using probe thermocouples (not shown) mounted directly upon a test boat or actually running short diffusions on test wafers to determine the optimum time delay required on the two end zones A1 and A3 as well as appropriate switching of the sections intermediate 13-14 and 16-19.

Still another timer X2 is incorporated with each furnace stack, and this timer X2 is used as a signalling device for indicating whether or not a possible malfunction has occurred in boat heat-up. Thus, since most semiconductor operations have multiple diffusion furnace installations and the diffusion operation itself is essentially an unattended one, the furnace is provided with malfunction protection. The recovery timer X2 is set to a time period also established empirically within which the recovery should be completed and to signal the operator if recovery has not occurred within that established time.

As may be seen from FIGURES 1, 2 and 12, each unit is equipped with a translucent light panel 88 which is adapted to illuminate the instrument panel 90 therebelow. Under ordinary circumstances, a white light lamp 112 is energized so as to direct a constant white illumination upon the panel 90. However, if the temperature of any zone A1, A2 or A3 deviates either above or below the temperature set point during a diffusion cycle, the light panel 88 changes from white to flashing red by actuation of red lamp 114. This would call the operator's attention to the malfunction and such would be further indicated by observation of the three temperature deviation meters 92, 94 and/or 96 on the panel 90.

Obviously, when a cool boat B is placed within the flat profiled furnace which is operating at the prescribed

temperature, the temperature will drop out of the operating band. Under these circumstances, the panel 88 flashes green as a result of actuation of green lamp 116, and this occurs for a predetermined period of time set on timer X2. The time setting of timer X2 is determined according to the heat-up time required for the particular load being used in the furnace. If after this preset period of time has expired and the furnace has still not reached temperature, the green lamp 116 will be de-energized and the red lamp 114 activated. Therefore, when the malfunction occurs during boat heat-up, the indication will be a change from flashing green to flashing red after the preset time on X2 has expired.

The main temperature controller is a three-function solid state proportioning controller especially designed for the low mass system, and in other aspects of its circuitry is generally conventional. However, in order to achieve stability afforded by the amplification sensitivity of such a circuit, the control package is mounted within a temperature controlled drawer 80 which includes its own heater 84 and circulating fan 86. See FIGURES 2 and 10. The drawer 80 is isolated from the remainder of the system and employs its own thermostat and control system which maintains all control components at a fixed temperature of operation above room ambient. By utilizing a fixed temperature reference of operation, the control system will not be affected by changes produced through heating up of its own elements nor by absorption from the adjacent furnace. Hence, the separate temperature controlled drawer prevents changes in the control system due to changes in ambient temperature. The drawer 80 is easily rolled in or out of the slide bracket 82 which is secured to a pair of the tie rods 62.

The power package for the diffusion furnace is mounted in the bottom of the cabinet. Reduced voltage for the heating element is supplied by three power transformers 120, 122 and 124 which are electrically coupled to the silicon controlled rectifier package 104, for example a Model W817A, three zone SCR power module made by Minneapolis-Honeywell. It is also to be observed that in addition to the magnetic contactors 130, 132 and 134 for activating the various zones of the SCR 104 and the respective power transformers 120, 122 and 124, there is also a power change switching contactor 128 which automatically switches the supply voltage to a lower temperature tap on the center zone transformer 122 just below the temperature control point. That is, it is desirable to supply full power to the coil C2 during initial temperature build-up of the furnace and during initial phases of boat recovery for maximum speed of response. However, once the temperature is achieved close to the control point, the automatic switching to a lower primary-to-secondary transformer ratio will prevent override and minimize power consumption.

Referring back to FIGURE 4, it is to be observed that the central zone A2 is defined intermediate the area bounded by the vertical broken lines indicated between the arrows A2. However, attention should be invited to the fact that the leads going from all of the terminals to the respective taps on the coil C are approximately twice the thickness or gauge of the heating coil itself in order to carry the current with minimal resistance. Consequently, if the taps 14, 13, 19 and 16 were drawn directly through the insulation D and E, there would be a heat sink created by conduction along the leads 14, 15, 17 and 16 from the coil C to the outside. That is, the center zone A2 of the furnace would be operating at an elevated temperature, 1300° C. for example, while the terminals 14, 15, 16 and 17 would be at ambient, perhaps 100° C. for example. Since the conduction of heat along the leads would ordinarily cause dips in the center of the zone A2, at taps 13 and 19, as well as depressing at the ends of the central zone A2, at the points where the leads 14 and 16 were tapped, it is necessary to avoid the situation.

Accordingly, as seen from FIGURE 4, the taps 13 and 19 are not drawn directly through the insulation D and E but are drawn under the first or second layer of insulation 20 and then outboard to a point well beyond the critical center zone A2 at 15 and 17 respectively. Similarly, the tapped leads at the end of the center coil C2 are drawn through the first layer of insulation 20 and then outwardly parallel to the chambers A1 and A3 respectively to positions at 14 and 16 outboard of the terminals 15 and 17. In this manner, the lead busses between 13 and 15 and between 17 and 19 are warmed and heated by the coil C itself even though the electrical source of heat energy is withdrawn from 13 and 19. Moreover, the heat from the end chambers A1 and A3 will warm the leading from 14 and 16 so as to prevent the heat loss or heat sink effect at the end of the center zone A2. Such a construction prevents depressions or dips in the temperature profile within the critical zone.

Referring now to the circuit diagram of FIGURES 13A and 13B, the mode of operation of the foregoing construction will now be explained in detail. All electrical circuit components are shown across a 220-volt, 3-phase line of FIGURE 13A, and at the right hand portion thereof, a control transformer 125 reduces the voltage to 115 volts across lines L1-L2. FIGURE 13B shows the power lines L1-L2 in across-the-line schematic form. Relays, motors and solenoid coils are indicated with encircled letters in a particular horizontal line. Relay contacts are designated with the same letter prefixes as the relay coils themselves bear. In addition, all relay contacts which are shown as being normally closed in the schematic will be identified with underlining in the specification. For example, the normally open R4-2 contacts in FIGURE 13A will have no underlining while the normally closed pair of R4-1 contacts are underlined. The entire FIGURE 13 schematic is shown in "power on" position with the furnace operating at set point.

The various timers are empirically set to time out for a pre-set period determined by past experience for a particular size boat B carrying a pre-determined number of wafers W. For example, timers X1 and X4 may be each set to operate for a period of 1.5 minutes, timers X3 and X5 each for a period of 6 minutes, and timer X2 for a period of 11 minutes. Since the furnace is at set point, 1300° C., and already flat profiled, just before the boat is inserted, all normally-closed Hi and Lo set point NUL contacts in the recovery system will be in closed position so that the five timer clutches CL will be engaged, and the white "flo" light 112 illuminated. Correspondingly, all normally-open Hi and Lo set point NUL contacts in the function signalling system will be open.

Placing a boat B through the left zone A1 into the center zone A2 will cause all control thermocouples to drop out of the operating range and actuate all NUL relay Lo set points. Therefore, the normally open NUL relay Lo contacts in the function signalling system close and actuate the green lights 116 and the flasher 140. All normally-closed Lo NUL contacts in the recovery system will open to effect the following conditions: white flo light 112 goes out and all timer clutch coils CL become de-energized.

De-energizing the timer clutch coils CL causes the motors M of the timers to be mechanically coupled with their respective timing gears and opens the normally-closed I contacts on timers X1, X3, X4 and X5. Opening the I contacts in the X1 and X3 timers de-energizes the left contactor coil LC and the right contactor coil RC which respectively open the LC and RC contacts 130 and 134. Accordingly, electrical power is cut to the left transformer 120 and hence to the left hand coil C1 as well as power to the right hand transformer 124 and hence to the right hand coil C3 for the respective periods of time set on X1 (1.5 minutes) and X3 (6 minutes).

At the same moment, the I contacts of timers X4 and X5 will open and thereby de-energize the R4 and R5 re-

lays which switch the R4-1 and R4-2 contacts and the R5-1 and R5-2 contacts to to operate the medial taps 13 and 19 rather than the end taps 14 and 16. Meanwhile, the center contactor coil CC will maintain the CC contacts closed so that power will be continued to the center zone. However, the switching coils CS will be de-energized as a result of opening of the center Lo NUL contacts and reverse the Hi-Lo CS contacts 128 so as to vary the turn ratio of the transformer 128 and accordingly drive more power to the center zone coil C2 during recovery.

When the timers X1 and X3 time out, their respective T.O. contacts will open and their T.C. contacts will close whereby the left contactor coil LC and right coil RC will be energized through the T.C. contacts. Thus, power delayed to the left and right heating coils C1 and C3 will now be resumed through the now closed LC and RC contacts 130 and 134. In a similar manner, timing out of the X4 and X5 timers will actuate the R4 and R5 relays and switch the center coil to end taps 14 and 16. During this period of recovery, thermocouple T2 has called for heat, and power has been received by the center zone A2 through the activation of the center NUL relay 106 via the Lo C NUL contacts. The thermocouples T1-T4 and T5-T3 have also called for power through the left NUL relay 108 and the right NUL relay 110. However, the time delay afforded through the timers X1 and X3 has prevented the supply of that power called for (by reflection) and hence precluded override of the temperatures called for by the set points.

When the temperature called for by the relays 108, 106 and 110 has exceeded that called for by their Lo set points, the L NUL, C NUL, and R NUL Lo contacts in the timer clutch circuit and the CS circuit will close thereby once more supplying power to the timer clutches, the white flo light 112, and the CS switching coil. Note that the various T.C. contacts of the timers are merely holding contacts across the I contacts, and power to the clutches causes the T.C. and T.O. to reverse and resupply motor M power.

When the temperature in the various zones A1, A2 and A3 has exceeded that called for by the Hi set points on the NUL meters 108, 106 and 110 respectively, all of the Hi NUL contacts in the recovery system circuit will open. Now, even though the I contacts are closed in the X1 and X3 timer circuits, the LC contactor coil, the CC contactor coil and the RC contactor coil will nevertheless be de-energized. Also, the flo light 112 will be de-illuminated. In the event that the recovery system does not return to an equilibrium temperature within the time set forth on the timer X2 (11 minutes), the T.C. contacts in the recovery timer will close thereby causing the red signal lamps to be energized across the center timer contacts T.C. Thus, after the pre-set period of time has elapsed on the timer X2, if the furnace has not reached temperature, the flashing lights change from green to red. Accordingly, if a malfunction occurs on boat "heat up," it is called to the operator's attention. When the furnace is heated from room temperature to control temperature, then lights will flash red and green until the unit reaches its control point.

Thus, a number of diffusion furnaces can be observed in their operation by observing the four different combinations of light arrangements discussed hereinabove. Furthermore, once a malfunction is signalled, the nature of the malfunction can be observed on the control panel 90. By observation of the meters the operator can determine whether the problem is improving or becoming worse.

It is to be particularly noted that one of the most critical factors in the satisfactory operation of the foregoing furnace is its very low mass. If the furnace were made of heavy insulating firebrick, the timer shutdown of the end zones would not have sufficient efficacy on boat temperatures to bring about flat boat heat up because of the heat storage in the massive firebrick.

Furthermore, the low mass of the instant furnace resulting from the use of light weight ceramic spacers 26 and the ceramic fiber lath or slats 20 secures stability immediately after each load, and enables the effect of recovery to be the same on each load. It is also to be noted that the pitch of the heating coil C may be varied and maintained in precise position by appropriate selection of size of the I-shape or H-spacers 26. The coil C itself forms the interior support for the insulation D while the aluminum sheath 28 defines the exterior support for the cartridge. Lastly, attention is invited to the fact that in lieu of timer X4 and X5, the timers X1 and X3 may perform the switching function from the taps 14 and 16 to 15 and 17 respectively as well, although the former system appears to provide greater flexibility.

Although this invention has been described in considerable detail, such description is intended as being illustrative rather than limiting, since the invention may be variously embodied, and the scope of the invention is to be determined as claimed.

What is claimed is:

1. A furnace for rapid diffusion of impurities into semiconductive slices at a uniformly flat elevated temperature comprising

an elongated insulated chamber including a central zone which is adapted to support a boat of semiconductive slices during diffusion, a first end zone through which the boat is passed into said central zone, and a second end zone forward of the boat opposite thereto,

heating means to elevate the temperatures of each of said zones independently,

sensing means in each of said zones for controlling said respective heating means and being set initially so that all of said zones are at the same temperature, and

means to cut-off the heating means for said second end zone for a predetermined period of time after the boat shall have been passed through said first zone whereby the actual temperature at the forward end of said boat will be prevented from overshooting the medial portion thereof during boat recovery.

2. The invention of claim 1 including switching means coupled with said central zone heating means and actuating only the intermediate portion thereof at the medial portion of the boat for a predetermined time so that the heat will be concentrated at the mass center of the boat in compensation of the greater surface to mass ratio at the ends thereof.

3. The invention of claim 1 including means to cut-off said heating means to the first end zone for a predetermined period of time after the boat shall have been passed through said first end zone.

4. The invention of claim 1 wherein said heating means comprises a helically-wound coil, and electrical power source means tapped into said coil across each zone.

5. The invention of claim 1 wherein said sensing means comprises a thermocouple mounted within the center of said central zone, a second thermocouple mounted in said central zone adjacent the first end zone, a third thermocouple mounted in said central zone adjacent said second end zone, a fourth thermocouple mounted in said first end zone, a fifth thermocouple mounted in said second end zone, said second and fourth thermocouples being coupled in series bucking disposition and said third and fifth thermocouples being coupled in series bucking disposition, first end zone control means registering the differential between said second and fourth thermocouples and automatically determining the difference in temperature between said first end zone and said central zone and sending a signal to said first end zone heating means in compensation of the difference, and second end zone control means registering the differential between said third and fifth thermocouples and automatically determining the difference in temperature between

said second end zone and said central zone and sending a signal to said second end zone heating means in compensation of the temperature difference.

6. The invention of claim 5 wherein said control means are mounted within a compartment isolated from said chamber, and auxiliary heating means within said compartment maintaining the environment therein at a constant temperature above room ambient.

7. The invention of claim 2 wherein each of said heating means comprises a helically-wound coil, first, central and second electrical power source means coupled respectively to said first, central and second zone coils, a pair of leads tapped in spaced-apart disposition into the medial portion of said central zone coil, layers of insulation concentrically disposed about said chamber, said tapped leads being bent adjacent the first layer and thereafter running longitudinally with said chamber so that the heat therein will warm said leads and thereby prevent dips in the temperature profile across the chamber otherwise occurring as a result of heat sinks at the tapped-in areas.

8. The invention of claim 4 including a plurality of I-shaped insulating elements of variable thickness interposed in circumferentially-spaced configuration intermediate adjacent loops of said coils so as to maintain the helical loops in spaced apart disposition with variable predetermined pitch so as to empirically control heat while at the same time contributing minimum mass.

9. The invention of claim 1 including strips of ceramic fiber insulation arranged circumferentially about the combined overall length of said heating means and in a plurality of annularly disposed layers thereabout.

10. The invention of claim 9 wherein the total thickness of the layers of insulation is such that said insulation will operate at its minimum K factor at the mean temperature of said chamber and the ambient temperature about said insulation thereby diminishing furnace mass and thus permitting faster heat-up and cool down rates with corresponding improvement in temperature profile across the length of the boat.

11. The invention of claim 9 including a pair of spaced leads tapped at one end into a medial portion of said central zone heating means, means at the other end of said spaced leads to switch and couple said central zone heating means with the medial portion of said central zone for a predetermined period of time during boat heat-up, said leads adjacent their points of tapped junction with said central zone heating means running intermediate the first and second layers of insulation about the chamber whereby the heat within the chamber will warm the leads to prevent depressions in temperature profile across the chamber which would otherwise occur from the heat sink created at the tapped-in junctions.

12. The invention of claim 3 including alarm means to indicate a malfunction, and timer means to actuate said alarm means when recovery has not occurred within an empirically predetermined period.

13. A diffusion furnace comprising an elongated insulated chamber including a central zone which is adapted to support a boat of semiconductive slices during diffusion, a first end zone through the boat is passed into said central zone, and a second end zone at the distal portion of said central zone,

heating means to elevate the temperatures of each of said zones independently,

first timer means to cut-off the heating means to said first end zone for a predetermined period after the boat shall have been passed therethrough into said central zone, and

second timer means to cut-off the heating means to said second end zone for a predetermined period after the boat has been passed into said central zone whereby the boat will be subjected to a flat temperature profile during recovery.

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14. The invention of claim 13 wherein said heating means comprises a helically-wound coil having a plurality of taps dividing said coil into five sections including a first section corresponding to said first end zone, a fifth section corresponding to said second end zone, a third section in the medial portion of said central zone and adapted for use with short boats, a second section intermediate said first and third sections, and a fourth section intermediate said third and fifth sections, means to cut-off power to said second section simultaneously with said first section, and means to cut-off power to said fourth section simultaneously with said fifth section whereby the second and fourth sections will be operative with said third section with relatively long boats and operative with said first and fifth sections for relatively short boats.

15. The invention of claim 13 including a third timer means to actuate a warning signal when recovery has not been effected within a predetermined empirically-ascertained period.

16. The invention of claim 14 wherein said means to cut-off power to said second and fourth sections respectively comprise third and fourth timer means.

17. A furnace for diffusion of semiconductive slices at a uniformly flat elevated temperature comprising a helically-wound heating coil, ceramic spacers interposed in circumferentially-spaced configuration intermediate adjacent loops of said coil and maintaining said loops in spaced-apart disposition at a predetermined pitch, slats of high temperature ceramic fiber insulation cir-

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cumferentially disposed in a plurality of annularly arranged longitudinally extending layers about said coil, and an outer metallic sheath wrapped around said slats and providing exterior support therefor, means for supporting said sheath in said furnace, said ceramic fiber insulation being selected to operate at minimum K-factor for the anticipated mean temperature of operation and at the flat portion of the temperature versus K curve so as to provide low mass whereby overshooting will be avoided.

18. The invention of claim 17 including an insulated outer shell spaced from and enclosing said insulation in said sheath.

19. The invention of claim 18 wherein said outer shell comprises a foamed polyurethane core laminated intermediate molded glass fiber panels.

20. The invention of claim 18 including tie rod and bolt means to secure said outer shell about said sheath.

21. The invention of claim 18 including means to blow air through the space between the outer shell and the sheath.

22. The invention of claim 21 including means to water cool the air being blown through the space.

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