PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : C03B 29/02, C23C 16/50, H01L 21/314, C23C 16/30, G05D 23/19	A1	(11) International Publication Number: WO 00/02824 (43) International Publication Date: 20 January 2000 (20.01.00)

(21) International Application Number: PCT/US99/15852

(22) International Filing Date: 13 July 1999 (13.07.99)

(30) Priority Data:
09/115,112 13 July 1998 (13.07.98) US

(71) Applicant: APPLIED KOMATSU TECHNOLOGY, INC. [JP/JP]; No. 1, 7 ban, 2–chome, Nishishinjuku, Tokyo (JP).

(71)(72) Applicant and Inventor: BEER, Emanuel [IL/US]; 7162 Via Vico, San Jose, CA 95129 (US).

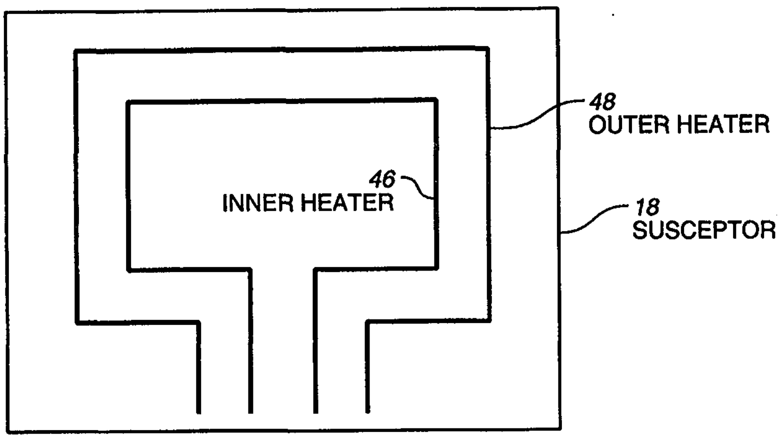
(72) Inventors: SHEN, Duoyan; Room 2, 540 South 8th Street, San Jose, CA 95112 (US). ZOHAR, Eitan; 6652 Clifford Court, Cupertino, CA 95014 (US). KOLLRACK, Marc, M.; 1369 19th Avenue, San Francisco, CA 94122 (US).

(74) Agents: BERNADICOU, Michael, A. et al.; Blakely, Sokoloff, Taylor & Zafman LLP, 7th floor, 12400 Wilshire Boulevard, Los Angeles, CA 90025 (US).

(81) Designated States: CN, JP, KR, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: HEATING A SUBSTRATE SUPPORT IN A SUBSTRATE HANDLING CHAMBER



(57) Abstract

A technique for heating a substrate support, such as a susceptor, includes establishing respective final temperature setpoints for first and second heating elements in the susceptor. The temperatures of the heating elements are raised to their respective final temperature setpoints based on a predetermined heating rate. The temperatures of the first and second heating elements are controlled so that the difference between the temperatures of the first and second heating elements does not exceed the predetermined value while the temperatures of the heating elements are raised to their respective final temperature setpoints. Controlling the temperatures includes setting interim setpoints for the first and second heating elements, where the interim setpoint for the heating element having the greater heating capacity depends on the current value of the interim setpoint of the other heating element and the predetermined value. The temperatures of the first and second heating elements are raised toward their respective interim temperature setpoints for a predetermined delay period. At the end of the delay period, new interim setpoints can be established and the process repeated until the temperature of at least one of the first and second heating elements is close to its respective final setpoint. A relatively high duty cycle can be achieved which also reduces the likelihood of deformation of the substrate support.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

HEATING A SUBSTRATE SUPPORT IN A SUBSTRATE HANDLING CHAMBER

Background

The present invention relates generally to substrate handling and processing chambers, and, in particular, to heating a substrate support in such chambers.

Glass substrates are being used for applications such as active matrix television and computer displays, among others. Each glass substrate can form multiple display monitors each of which contains more than a million thin film transistors.

The glass substrates can have dimensions, for example, of 550 mm by 650 mm. The trend, however, is toward even larger substrate sizes, such as 650 mm by 830 mm and larger, to allow more displays to be formed on the substrate or to allow larger displays to be produced. The larger sizes place even greater demands on the capabilities of the processing systems.

The processing of large glass substrates often involves the performance of multiple sequential steps, including, for example, the performance of chemical vapor deposition (CVD) processes, physical vapor deposition (PVD) processes, or etch processes. Systems for processing glass substrates can include one or more process chambers for performing those processes.

Plasma-enhanced chemical vapor deposition (PECVD) is another process widely used in the processing of glass substrates for depositing layers of electronic materials on the substrates. In a PECVD process, a substrate is placed in a vacuum deposition chamber equipped with a pair of parallel plate electrodes. The substrate generally is mounted on a susceptor which also serves as the lower electrode. A flow of a reactant gas is provided in the deposition chamber through a gas inlet manifold which also serves as the upper electrode. A radio frequency (RF) voltage is applied between the two electrodes which generates an RF power sufficient to cause a plasma to be formed in the reactant gas. The plasma causes the reactant gas to decompose and deposit a layer of the desired material on the surface of the substrate body. Additional layers of other electronic materials can be deposited on the first layer by flowing another reactant gas into the chamber. Each reactant gas is subjected to a plasma which results in the deposition of a layer of the desired material.

Some problems associated with the processing of large glass substrates arise due to their unique thermal properties. For example, the relatively low thermal conductivity of glass makes it more difficult to heat or cool the substrate uniformly. In particular, thermal losses near the edges of any large-area, thin substrate tend to be greater than near the center of the substrate, resulting in a non-uniform temperature gradient across the substrate. The thermal properties of the glass substrate combined with its size, therefore, makes it more difficult to obtain uniform characteristics for the electronic components formed on different portions of the surface of a processed substrate. Moreover, heating or cooling the substrates quickly and uniformly is more difficult as a consequence of its poor thermal conductivity, thereby posing special challenges to achieving a high throughput.

To help obtain a more uniform temperature across large substrates, susceptors having multiple heating elements have been used. For example, some susceptors include inner and outer heating elements. The use of multiple heating elements, however, occasionally results in the susceptor becoming deformed as it is heated. One cause of the deformation is a temperature differential that can occur between the inner and outer heating elements. If the temperature differential, or gap, becomes too large, the thermal stresses in the susceptor can result in deformation of the susceptor and, in some instances, even breakage.

Summary

In general, in one aspect, a method of heating a substrate support includes establishing respective final temperature setpoints for first and second heating elements of the substrate support. The difference in temperatures of the first and second heating elements is caused to be less than a predetermined value ΔT, if the difference initially exceeds the predetermined value. The temperatures of the heating elements then are raised to their respective final temperature setpoints T_{F1}, T_{F2} based on a predetermined heating rate R. Furthermore, the temperatures of the first and second heating elements are controlled so that the difference between the temperatures of the first and second heating elements does not exceed the predetermined value ΔT while the temperatures of the heating elements are raised to their respective final temperature setpoints.

In general, the final temperature setpoints of the heating elements need not be the same. Controlling the temperatures of the heating elements can include setting a first interim temperature setpoint for the first heating element and setting a second interim temperature setpoint for the second heating element. The second interim setpoint depends on the current value of the first interim setpoint and the predetermined value ΔT. The temperatures of the first and second heating elements then are raised toward their respective interim

temperature setpoints for a predetermined delay period. At the end of the delay period, new interim setpoints can be established and the process repeated until the temperature of at least one of the first and second heating elements is within a predetermined amount of its respective final setpoint.

In some implementations, the second interim value used for the second heating element is set equal to the current value of the first interim setpoint plus the predetermined value ΔT. The value of the first interim setpoint can depend on the current temperature of the first heating element and the predetermined heating rate R. For example, the first interim setpoint can be set equal to the sum of the current temperature of the first heating element and the value of the predetermined heating rate R.

In another aspect, a substrate handling apparatus includes a substrate processing chamber and a substrate support disposed in the chamber. The substrate support includes first and second heating elements for heating the substrate support and a controller for controlling the temperature of the heating elements according to the foregoing techniques.

In some implementations, the first and second heating elements are inner and outer heating elements embedded within the substrate, respectively. In addition, the heating elements can have different heating capacities. For example, according to one implementation, the second heating element has a heating capacity greater than the heating capacity of the first heating element.

The techniques described herein are not limited to a substrate support having only two heating elements. Rather, the techniques are applicable to the heating of substrate supports with more than two heating elements or more than two heating zones.

In addition, in various implementations, one or more of the final temperature setpoints for the heating elements, the predetermined heating rate R, and the predetermined value ΔT can be selected by the user, thereby providing a flexible technique which easily can be modified for different systems or configurations.

Various implementations include one or more of the following advantages. The rate at which the interim temperature setpoints for each of the heating elements is increased is designed to be as high as the predetermined heating rate R, within the limitations, for example, of the capabilities of the heating elements. Each time the heating elements approach the current interim setpoints, the interim setpoints can be increased, thereby maintaining a relatively high duty cycle. Maintaining a limited temperature gap between the heating elements and increasing the interim temperature setpoints toward the final setpoints causes heat transfer from the heating element with the greater heating capacity to the heating element with the lower heating capacity. The heating element with the greater heating capacity, therefore, works at a duty cycle that is higher than the duty cycle it would have used solely for its own heating. In other words, the power of the heating element with the greater capacity is used to increase the temperature of regions of the substrate support near the heating element with the lower heating capacity.

Moreover, by limiting the difference between the interim temperature setpoints to a predetermined value, the likelihood that the temperature difference between the heating elements will exceed the predetermined value ΔT is reduced. That, in turn, can substantially reduce the likelihood of deformation and breakage of the substrate support if the predetermined value ΔT is selected carefully.

Other features and advantages will be apparent from the following detailed description, accompanying drawings and claims.

Brief Description of the Drawings

FIG. 1 illustrates an exemplary thermal deposition chamber.

FIG. 2 illustrates an exemplary substrate support for the chamber of FIG. 1.

FIG. 3 illustrates a glass substrate placed on the substrate support of FIG. 2.

FIG. 4 shows a control system for controlling the temperature of the substrate support of FIG. 2 according to the invention.

FIGS. 5A and 5B are a flow chart illustrating a method of heating the substrate support of FIG. 2 according to the invention.

Detailed Description

Referring to FIG. 1, a plasma-enhanced chemical vapor deposition apparatus 10 includes a deposition chamber 12 having an opening through a top wall 14 and a first electrode or a gas inlet manifold 16 within the opening. Alternatively, the top wall 14 can be solid with the electrode 16 adjacent to the inner surface of the top wall. A substrate support, such as a susceptor 18 in the form of a plate, extends within the chamber 12 parallel to the first electrode 16. The susceptor 18 is formed of aluminum and can be coated with a layer of aluminum oxide. Embedded within the susceptor 18 are a first, or inner, heating element 46 and a second, or outer, heating element 48 (FIG. 2), which can be formed, for example, as heating coils. In some implementations, the heating elements 46, 48 need not be embedded within the susceptor 18 as long as they are in thermal contact with the susceptor or other substrate support.

Although the heating capacity of the heating elements 46, 48 can be the same, in one implementation, the outer heating element 48 has a relatively high heating capacity, whereas the inner heating element 46 has a relatively low heating capacity. For example, in the illustrated implementation, approximately 40 kilo-Watts (kW) are supplied to the outer heating element 48, and approximately 20 kW are supplied to the inner heating element 46. Providing more power to the outer heating element 48 can help compensate for thermal losses which typically are greater near the outer perimeter of the susceptor 18. In other implementations, however, the inner heating element 46 can be more highly powered than the outer heating element 48, and the role of the inner and outer heating elements 46, 48 can be reversed. To provide the heating elements 46, 48 with different heating capacities, different power sources can be used. Alternatively, a common source can be used, and the heating capacity of the heating elements 46, 48 can be made to differ by forming the heating elements from different materials. The selection of which heating element should be provided with a larger heating capacity depends, among other things, on the size of respective zones on the susceptor 18 which the heating elements 46, 48 are intended to heat. In any event, providing the heating elements 46, 48 with different heating capacities can be particularly important in the processing of glass substrates having dimensions of 650 mm by 830 mm and higher due to the large size of such substrates as well as the thermal properties of the glass.

The susceptor 18 is connected to ground so that it serves as a second electrode and is mounted on the end of a shaft 20 (FIG. 1) which extends vertically through a bottom wall 22 of the chamber 12. The shaft 20 is movable vertically to permit the vertical movement of the susceptor 18 toward and away from the first electrode 16.

A lift-off plate 24 extends horizontally between the susceptor 18 and the bottom wall 22 of the chamber 12 substantially parallel to the susceptor and is movable vertically. Lift-off pins 26 project vertically upward from the lift-off plate 24. The lift-off pins 26 are positioned to be able to ext nd through lift holes 28 in the susceptor 18, and have a length slightly longer than the thickness of the susceptor. While only two lift-off pins 26 are shown in FIG. 1, there may be additional lift-off pins spaced around the lift-off plate 24.

A gas outlet 30 extends through a side wall 32 of the chamber 12 and is connected to a system (not shown) for evacuating the chamber. A gas inlet pipe 42 extends into the gas inlet manifold 16 and is connected through a gas switching network to sources of various gases (not shown). The first electrode 16 is connected to an RF power source 36. A transfer mechanism (not shown) can be provided to carry a substrate 38 through a load-lock door into the deposition chamber 12 where the substrate can be transferred onto the susceptor 18 (FIGS. 1 and 3). The transfer mechanism also is used to remove the processed substrate from the chamber.

Prior to transferring a substrate 38 onto the susceptor 18, the susceptor is pre-heated to a desired temperature, for example, approximately 400 °C. As described in greater detail below, a temperature controller 50 (FIG. 4), such as a computer or other processor, controls the temperature of the heating elements 46, 48. The controller 50 is programmed with software and configured to perform the functions described below. Thermocouples 52 can be used to measure the temperature of the heating elements 46, 48 and are coupled to the controller 50 to provide such information to the controller.

The software allows a user to enter values for several variables, including final setpoints T_{F1}, T_{F2}, for the temperature of the inner and outer heating elements 46, 48. The values of the user-defined variables can be entered, for example, using a keyboard 54 or other input device coupled to the controller 50. The final setpoints T_{F1}, T_{F2} for the heating elements 46, 48 may differ from one another. Providing different setpoints allows heat flow from one area of the susceptor 18 to another area to be controlled more precisely, as described in greater detail below. Such heat flow can be desirable to compensate for the large size and relatively poor thermal properties of the glass substrates.

The software also allows the user to select the value of a heating rate R that defines an approximate rate (°C/minute) at which the temperatures of the heating elements 46, 48 increase. In one exemplary embodiment, R is set to 10 °C per minute. An interlock in the software prevents a value of R from being used if it would overheat or otherwise damage the system. If a value of R is selected by the user which exceeds a maximum rate, then the system can be shut off or a maximum default value for the rate R can be used.

In some implementations, the user also enters a maximum allowable value for the difference ΔT between the measured temperature T_1 of the inner heating element 46 and the measured temperature T_2 of the outer heating element 48. In other implementations, however, the value of ΔT is preset in the software and is not defined by the user. In any event, the value of ΔT is determined prior to heating the susceptor 18. In one exemplary embodiment, the value of ΔT is set to 20 °C, although other values also can be used depending on the particular construction of the susceptor 18 and the process to be performed. The user-defined values are stored in memory 56.

Referring to FIGS. 5A and 5B, once the user has entered the value of the user-defined variables, including the values for the final setpoints T_{F1}, T_{F2} and the heating rate R, those values are read from memory 56 (step 100). If the value for ΔT is set by the user, then it also is retrieved from memory. Various Boolean-type and other variables are initialized (step 102). For example, a Boolean flag F initially is set to "false." The state of the flag F is changed to "true" if the temperature of the inner heating element 46 is lower than a predetermined amount T_s below the final setpoint T_{F1}, in other words, if

$T_1 < T_{F1} - T_s$. In one embodiment, for example, the predetermined amount T_s is 5 °C. Thus, if the final setpoint T_{F1} were set to 400 °C, the flag F changes to "true" if the temperature of the inner heating element 46 is less than 395 °C. In addition, if the value of ΔT is not set by the user, then the value of ΔT also would be initialized in step 102.

A determination then is made as to whether either the temperature T_1 of the inner heating element 46 or the temperature T_2 of the outer heating element 48 is above its respective final setpoint T_{F1}, T_{F2} (step 104). When the system is first turned on, both heating elements 46, 48 normally will be below their final setpoints. However, if the determination in step 104 is affirmative, then both heating elements 46, 48 are shut off (step 106). The controller 50 waits a predetermined time (step 108), for example, 30 seconds, and then returns to step 104 to check the temperatures T_1, T_2. The controller 50 continues to cycle through the loop formed by steps 104-

108 until both heating elements 46, 48 are below their respective final setpoints T_{F1}, T_{F2}. The controller 50 then initializes the heating elements 46, 48 by making power available to them (step 110).

Next, the controller 50 executes a pre-heating preparation stage to ensure that the difference between the current temperatures T_1, T_2 of the heating elements 46, 48 does not exceed the maximum allowable difference ΔT. Therefore, a determination is made as to whether the value of T_1 minus T_2 exceeds the value of ΔT (step 112). If the value does not exceed ΔT, in other words if the temperature difference between the inner and outer heating elements 46, 48 is not too large, then the controller 50 proceeds to execute a preliminary susceptor heating process that raises the temperature of the susceptor 18 to the desired final setpoints, as described below.

On the other hand, if in step 112 it is determined that the difference between T_1 and T_2 exceeds ΔT, then the hotter heating element, for example, the outer heating element 48, is turned off, and the remaining heating element 46 is heated (step 114). During step 114, an interim setpoint $T_{1(INT)}$ is established for the temperature of the inner heating element 46, where

$$T_{1(INT)} = T_1 + [(R) \times (\text{minute})].$$

In addition, during step 114 the inner heating element 46 is allowed to heat up at a maximum greater than the value of R. For example, in one implementation, the inner heating element 46 is permitted to heat up at a maximum rate equal to twice the value of R. Of course, the actual rate at which the inner heating element heats up during this step may be limited by the physical capabilities of the heating element. The controller 50 then waits for a pre-determined delay period to elapse (step 116). The pre-determined delay can be, for example, thirty seconds. During the delay period, the temperature of the inner heating element 46 is not permitted to exceed the current value of $T_{1(INT)}$. At the end of the delay period, the controller 50 returns to step 112 to determine whether the value of T_1 minus T_2 exceeds the value of ΔT. The controller continues to execute the loop formed by steps 112-116 until the difference between the temperature T_1 of the inner heating element and the temperature T_2 of the outer heating element does not exceed ΔT. The controller 50 then executes a preliminary susceptor heating process that raises the temperature of the susceptor 18 to the desired final setpoints.

Although the algorithm executed by the controller 50 helps ensure that the difference between the temperatures of the heating elements does not exceed ΔT, maintaining a non-zero gap between the temperatures of the heating elements that is less than ΔT can result in a heat flow between areas of the susceptor 18 that allows the susceptor to heat up more quickly and more efficiently. Thus, as described more fully below, the higher heating capacity of the outer heating element 48, for example, can be used to augment heating by the inner heating element 46.

In general, the preliminary susceptor heating process, as described below, is designed to allow the susceptor 18 to be heated to its final temperature as quickly as possible based on the rate R selected by the user while maintaining the difference between the temperatures of the heating elements 46, 48 at a value less than ΔT. Both heating elements are turned on (step 118) and a determination is made as to whether either the temperature T_1 of the inner heating element 46 is less than T_{F1} minus T_s or whether the temperature T_2 of the outer heating element 48 is less than T_{F2} minus T_s (step

120). If both heating elements 46, 48 are close to their respective final setpoints, in other words, if the determination in step 120 is negative, then interim setpoints $T_{1(INT)}$ and $T_{2(INT)}$ for both heating elements are set to the respective final setpoints T_{F1}, T_{F2} to allow the susceptor 18 to heat up to its final temperature (step 140). The preliminary susceptor heating process then would be completed, and the controller 50 would control the heating elements 46, 48 to maintain the susceptor temperature at the desired level.

On the other hand, if the determination in step 120 is affirmative, in other words, if the temperature of at least one of the heating elements 46, 48 is not close to its respective final setpoint, then a determination is made as to whether the temperature T_1 of the inner heating element 46 is less than T_{F1} minus T_s (step 124). If the determination is answered in the negative, in other words, if the temperature of the inner heating element 46 is close to its final setpoint T_{F1}, then the flag F is cleared to "false", and the interim setpoint $T_{1(INT)}$ for the inner heating element 46 is set to the final setpoint T_{F1} (step 126).

If the determination in step 124 is answered in the affirmative, in other words, if the temperature T_1 of the inner heating element 46 is not close to its final setpoint T_{F1}, then the flag F is set to "true" (step 128). In addition, the interim setpoint $T_{1(INT)}$ for the temperature of the inner heating element 46 is set equal to the current temperature T_1 of the inner heating element plus the value of the heating rate R (step 130), in other words, $T_{1(INT)} = T_1 + [(R) \times (minute)]$.

Regardless of whether the algorithm follows step 126 or steps 128-130, the controller 50 proceeds to make a determination as to whether three conditions are satisfied (step 132). First, the flag F must be set to "true," in other words, the temperature T_1 of the inner heating element 46 must be less than its final setpoint T_{F1} by at least T_s. Second, the temperature T_2 of the outer heating element 48 also must be well below its final setpoint, in other words, $T_2 < T_{F2} - T_s$. Third, the sum of ΔT and the current interim setpoint $T_{1(INT)}$ established for the inner heating element 46 must be less than the final setpoint T_{F2} for the outer heating element, in other words, $\Delta T + T_{1(INT)} < T_{F2}$. This last condition helps prevent the outer heating element 48 from overshooting the final setpoint T_{F2} if the algorithm proceeds to step 136.

If one or more of those three conditions is not satisfied, then an interim setpoint $T_{2(INT)}$ for the outer heating element 48 is set equal to the final setpoint T_{F2} (step 134). The controller 50 then waits for a predetermined delay period to elapse (step 138). The predetermined delay can be, for example, sixty seconds, although other delays may be appropriate in some situations. At the end of the delay period, the controller 50 returns to step 120.

On the other hand, if all three conditions in step 132 are satisfied, the interim setpoint $T_{2(INT)}$ for the outer heating element 48 is set, as indicated by step 136, according to:

$$T_{2(INT)} = T_{1(INT)} + \Delta T.$$

The controller 50 then waits for a predetermined delay period to elapse (step 138). The predetermined delay can be, for example, sixty seconds, although other delays may be appropriate in some situations. At the end of the delay period, the controller 50 returns to step 120.

In general, during the delay period of step 138, the temperature T_1 of the inner heating element 46 should not exceed the current value of $T_{1(INT)}$, and the temperature T_2 of the outer heating element 48 is not permitted to exceed the current value of $T_{2(INT)}$. By making the values of $T_{1(INT)}$ and $T_{2(INT)}$ dependent on one another as expressed by the equation in step 136, the likelihood that the difference between the temperatures T_1, T_2 of the heating elements 46, 48 will become too large is greatly reduced. Thus, the susceptor 18 can be heated to its final temperature based on the rate R selected by the user and, at the same time, in a manner that substantially reduces the possibility of susceptor breakage.

The controller 50 continues to execute the loop formed by steps 120-138 until the temperatures T_1, T_2 of both heating elements 46, 48 are close to their respective final setpoints T_{F1}, T_{F2} so that the interim setpoints $T_{1(INT)}$, $T_{2(INT)}$ can be set equal, respectively, to T_{F1}, T_{F2} (step 140). Once the heating elements 46, 48 reach their respective final setpoints T_{F1}, T_{F2}, the preliminary susceptor heating process is completed, and the controller 50 controls the heating elements 46, 48 to maintain the susceptor temperature at its desired final temperature. A substrate then can be transferred onto the susceptor 18 for heating and processing.

The rate at which the interim temperature setpoints for each of the heating elements 46, 48 are increased is designed to be as high as the rate R selected by the user, although the actual heating rate may be limited by the heating capacities of the heating elements or other factors. Each time the heating elements 46, 48 approach the current interim setpoints, the interim setpoints are increased, thereby maintaining a relatively high duty cycle. Maintaining a limited temperature gap between the heating elements 46, 48 and constantly increasing the interim temperature setpoints causes heat transfer from the heater with the greater heating capacity (e.g., the outer heating element 48) to the heater with the lower heating capacity (e.g., the inner heating element 46). The heating element with the greater heating capacity, therefore, works at a duty cycle that is higher than the duty cycle it would have used solely for its own heating. In other words, the power of the heating element with the greater capacity is used to increase the temperature of regions of the susceptor near the heating element with less capacity.

Furthermore, while the implementation discussed above has been described for a substrate support having two heating elements, the foregoing technique can be used to heat a substrate support having more than two heating elements as well. In such a configuration, all the heating elements, except the coolest heating element, can be treated like the outer heating element described above such that the difference in temperature between the coolest heating element and each one of the other heating elements does not exceed the predetermined value ΔT.

In addition, the foregoing technique can be used in connection with substrate supports other than susceptors, such as heating platens, and in substrate handling systems using techniques other than PECVD. For example, the technique can be incorporated a wide variety of substrate handling systems in which a substrate is heated. The technique also can be used to control the heating of a substrate support in chambers other than process chambers, such as pre-heating or load lock chambers. Additionally, the technique described above can be used for heating substrate supports for substrates made of materials other than glass.

Other implementations are within the scope of the following claims.

What is claimed is:

1. A thermal substrate handling apparatus comprising:

a processing chamber;

a substrate support disposed in the chamber, the substrate support including first and second heating elements for heating the substrate support; and

a controller for controlling the temperature of the heating elements;

wherein the controller controls the temperatures of the first and second heating elements so that, if a difference in temperatures between the first and second heating elements initially exceeds a predetermined value, the difference is caused to be less than the predetermined value; and

wherein the controller controls the temperatures of the first and second heating elements so that while the temperatures of the heating elements are raised to respective final temperature setpoints, the difference between the temperature of the first heating element and the temperature of the second heating element does not exceed the predetermined value.

2. The apparatus of claim 1 wherein the final temperature setpoint of the first heating element is different than the final temperature setpoint of the second heating element.

3. The apparatus of claim 1 wherein the controller is configured to control the temperature by

(a) setting a first interim temperature setpoint for the first heating element;

(b) setting a second interim temperature setpoint for the second heating element, wherein the second interim setpoint depends on a current value of the first interim setpoint and the predetermined value; and

(c) raising the temperatures of the first and second heating elements toward their respective interim temperature setpoints.

4. The apparatus of claim 3 wherein the controller is configured to

(d) allow the temperatures of the first and second heating elements to rise toward their respective interim setpoints for a predetermined delay period;. and

(e) repeat steps (a), (b, (c) and (d) until the temperature of at least one of the first and second heating elements is within a predetermined amount of its respective final setpoint.

5. The apparatus of claim 3 wherein the controller is configured to set the second interim value equal to a current value of the first interim setpoint plus the predetermined value.

6. The apparatus of claim 3 wherein the controller is configured to calculate the value of the first interim setpoint based on a current temperature of the first heating element and a predetermined heating rate.

7. The apparatus of claim 3 wherein the controller is configured to set the first interim setpoint equal to the current temperature of the first heating element plus the value of a predetermined heating rate.

8. The apparatus of claim 7 wherein the controller is configured to:

(d) set the second interim value equal to the current value of the first interim setpoint plus the predetermined value;

(e) allow the temperatures of the first and second heating elements to rise toward their respective interim setpoints for a predetermined delay period; and

(f) repeat steps (a), (b), (c), (d) and (e) until the temperature of at least one of the first and second heating elements is within a predetermined amount of its respective final setpoint.

9. The apparatus of claim 3 wherein the first heating element is an inner heating element embedded within the substrate support and the second heating element is an outer heating element embedded within the substrate support.

10. The apparatus of claim 3 wherein the first heating element has a first heating capacity and the second heating element has a second heating capacity greater than the first heating capacity.

11. The apparatus of claim 3 wherein the controller is configured to execute the following functions if the difference in temperatures of the first and second heating elements initially is not less than the predetermined value:

(d) turn off the second heating element; and

(e) allow the first heating element to heat up while the second heating element is turned off.

12. The apparatus of claim 11 wherein the controller further is configured to execute the following functions:

(f) allow the first heating element to heat up for a predetermined period of time; and

(g) check whether the difference between the temperatures of the heating elements exceeds the predetermined value upon completion of the predetermined period of time.

13. The apparatus of claim 12 wherein the controller further is configured to execute the following functions:

repeat functions (d), (e), (f) and (g) until the difference between the temperatures of the heating elements no longer exceeds the predetermined value.

14. The apparatus of claim 12 wherein the controller is configured to allow the first heating element to heat up at a maximum rate that exceeds a predetermined heating rate while the second heating element is turned off.

15. A method of heating a substrate support, the method comprising:

establishing respective final temperature setpoints for first and second heating elements of the substrate support;

causing a difference in temperatures of the first and second heating elements to be less than a predetermined value, if the difference initially exceeds the predetermined value;

raising the temperatures of the heating elements to their respective final temperature setpoints based on a predetermined heating rate; and

controlling the temperatures of the first and second heating elements so that the difference between the temperature of the first heating element and the temperature of the second heating element does not exceed the predetermined value while the temperatures of the heating elements are raised to their respective final temperature setpoints.

16. The apparatus of claim 15 wherein the final temperature setpoint of the first heating element is different than the final temperature setpoint of the second heating element.

17. The method of claim 15 wherein controlling the temperatures includes:

(a) setting a first interim temperature setpoint for the first heating element;

(b) setting a second interim temperature setpoint for the second heating element, wherein the second interim setpoint depends on a current value of the first interim setpoint and the predetermined value; and

(c) raising the temperatures of the first and second heating elements toward their respective interim temperature setpoints.

18. The method of claim 17 further including:

(d) allowing the temperatures of the first and second heating elements to rise toward their respective interim setpoints for a predetermined delay period; and

(e) repeating steps (a), (b, (c) and (d) until the temperature of at least one of the first and second heating elements is within a predetermined amount of its respective final setpoint.

19. The method of claim 17 wherein the second interim value equals a current value of the first interim setpoint plus the predetermined value.

20. The method of claim 17 wherein the value of the first interim setpoint depends on the current temperature of the first heating element and the predetermined heating rate.

21. The method of claim 17 wherein the first interim setpoint is set equal to a current temperature of the first heating element plus the value of the predetermined heating rate.

22. The method of claim 21 wherein the second interim value equals the current value of the first interim setpoint plus the predetermined value, the method further including:

(d) allowing the temperatures of the first and second heating elements to rise toward their respective interim setpoints for a predetermined delay period; and

repeating steps (a), (b, (c) and (d) until the temperature of at least one of the first and second heating elements is within a predetermined amount of its respective final setpoint.

23. The method of claim 17 wherein the first heating element is an inner heating element embedded within the substrate support and the second heating element is an outer heating element embedded within the substrate support.

24. The method of claim 17 wherein the first heating element has a first heating capacity and the

second heating element has a second heating capacity greater than the first heating capacity.

25. The method of claim 17 wherein causing the difference in temperatures of the first and second heating elements to be less than the predetermined value includes:

(d) turning off the second heating element prior to the step of controlling, if the difference between the temperatures of the heating elements exceeds the predetermined value; and

(e) allowing the first heating element to heat up while the second heating element is turned off.

26. The method of claim 25 wherein the first heating element is allowed to heat up for a predetermined period of time, the method further including:

(f) checking whether the difference between the temperatures of the heating elements exceeds the predetermined value upon completion of the predetermined period of time.

27. The method of claim 26 further including:

repeating steps (d), (e) and (f) until the difference between the temperatures of the heating elements no longer exceeds the predetermined value.

28. The method of claim 26 wherein the first heating element is allowed to heat up at a maximum rate that exceeds the predetermined heating rate while the second heating element is turned off.

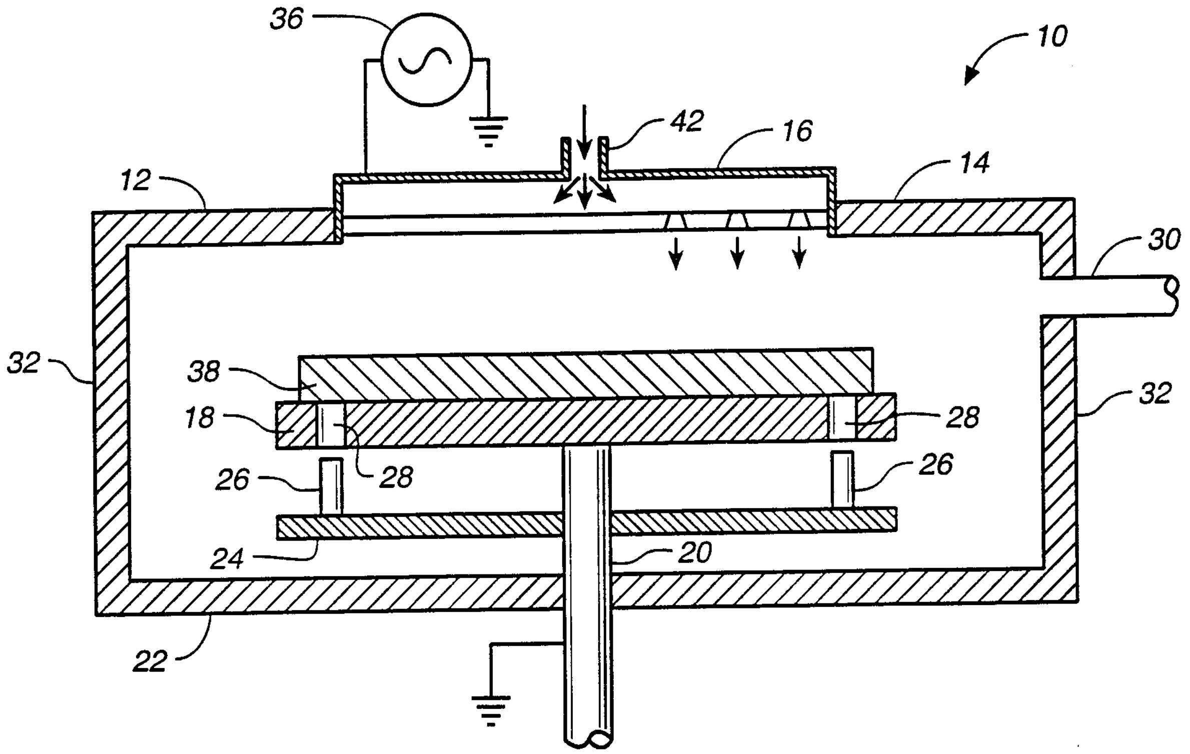

36
10
42
16
12
14
30
32
38
18
28
26
28
26
32
24
20
22

FIG._1

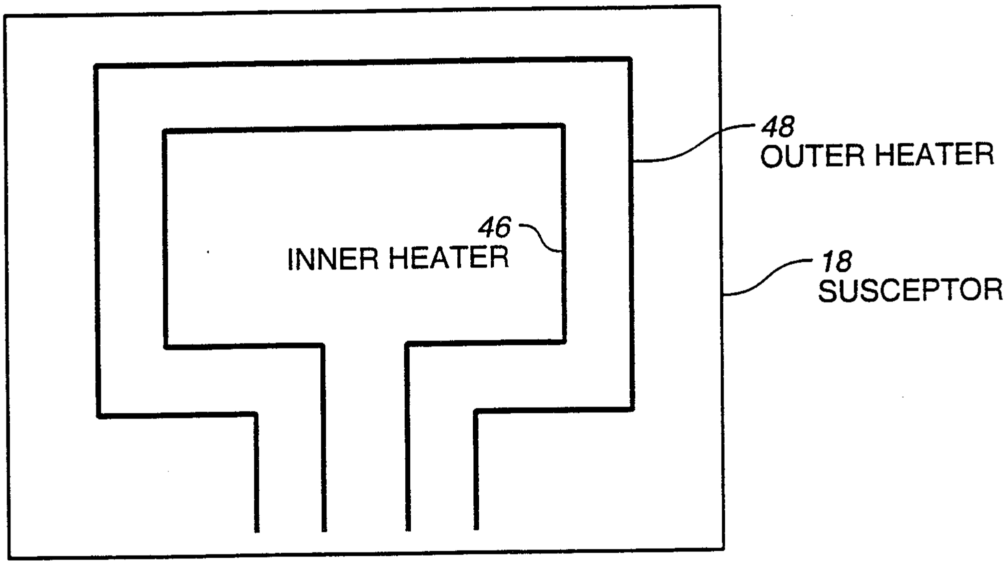

48
OUTER HEATER
46
INNER HEATER
18
SUSCEPTOR

FIG._2

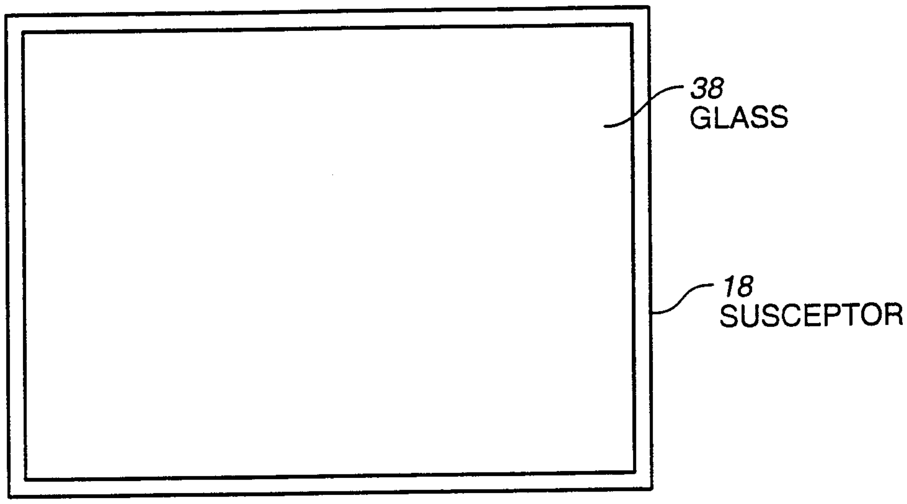

38
GLASS
18
SUSCEPTOR

FIG._3

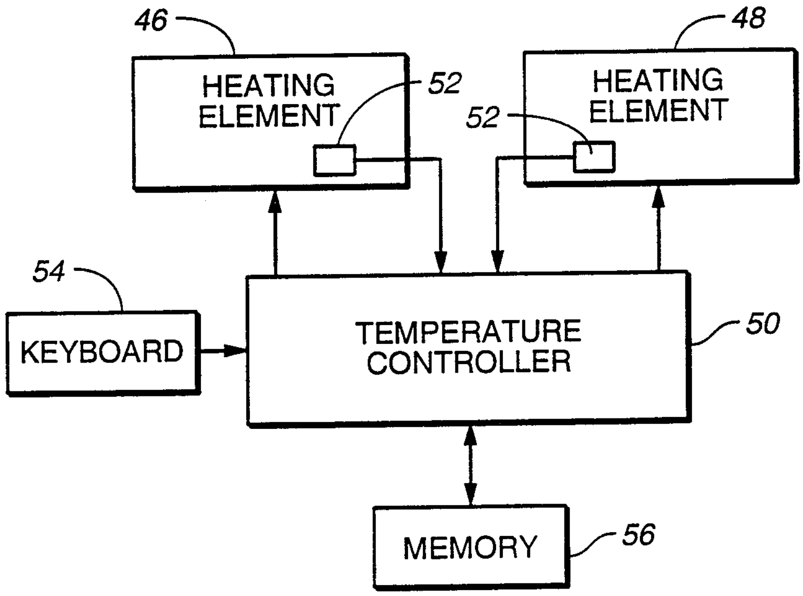

46
48
HEATING ELEMENT
52
52
HEATING ELEMENT
54
KEYBOARD
TEMPERATURE CONTROLLER
50
MEMORY
56

FIG._4

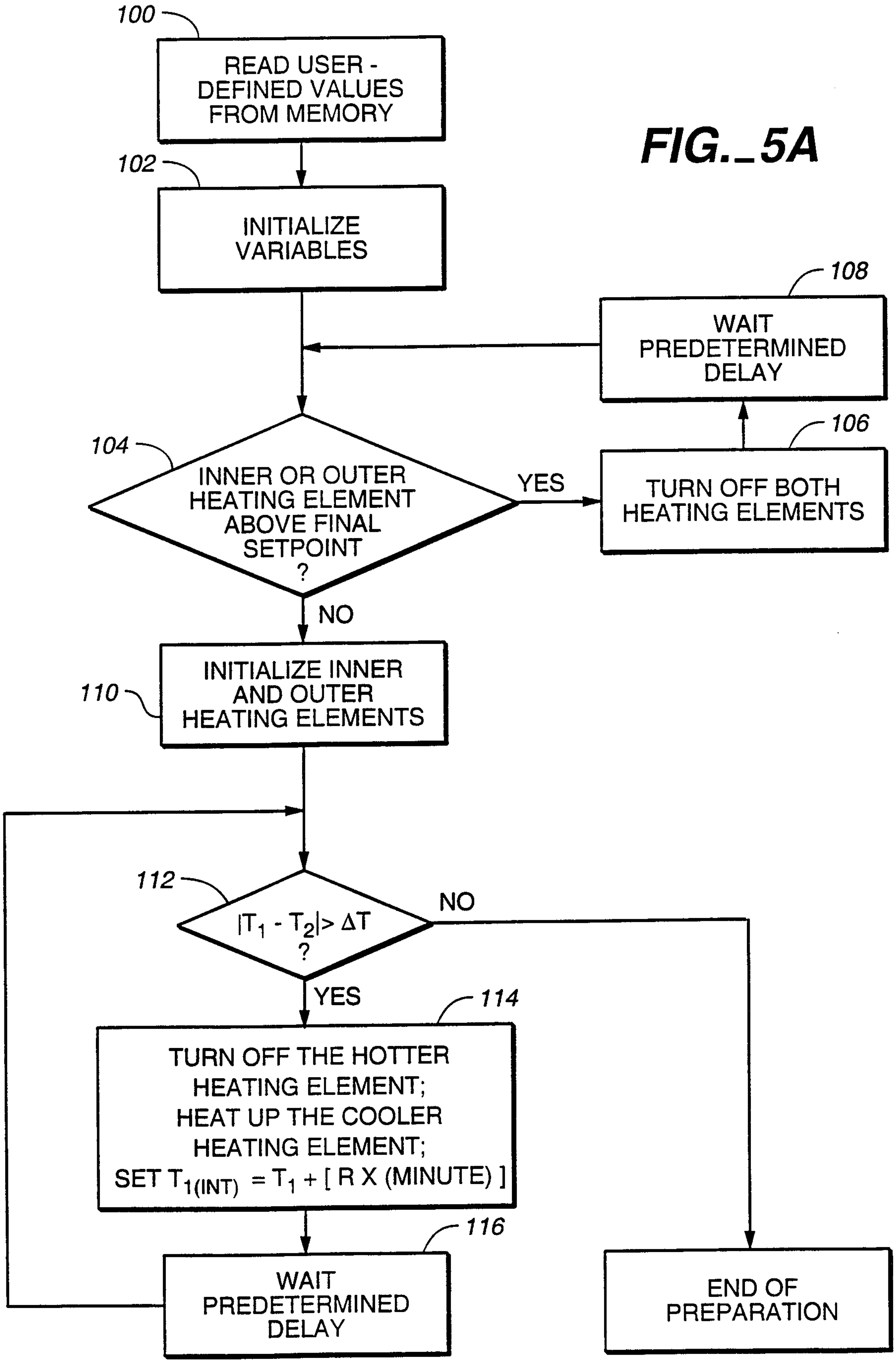

100
READ USER - DEFINED VALUES FROM MEMORY
102
INITIALIZE VARIABLES
108
WAIT PREDETERMINED DELAY
106
TURN OFF BOTH HEATING ELEMENTS
104
INNER OR OUTER HEATING ELEMENT ABOVE FINAL SETPOINT ?
YES
NO
110
INITIALIZE INNER AND OUTER HEATING ELEMENTS
112
|T1 - T2|> ΔT ?
NO
YES
114
TURN OFF THE HOTTER HEATING ELEMENT; HEAT UP THE COOLER HEATING ELEMENT; SET T1(INT) = T1 + [R X (MINUTE)]
116
WAIT PREDETERMINED DELAY
END OF PREPARATION

FIG._5A

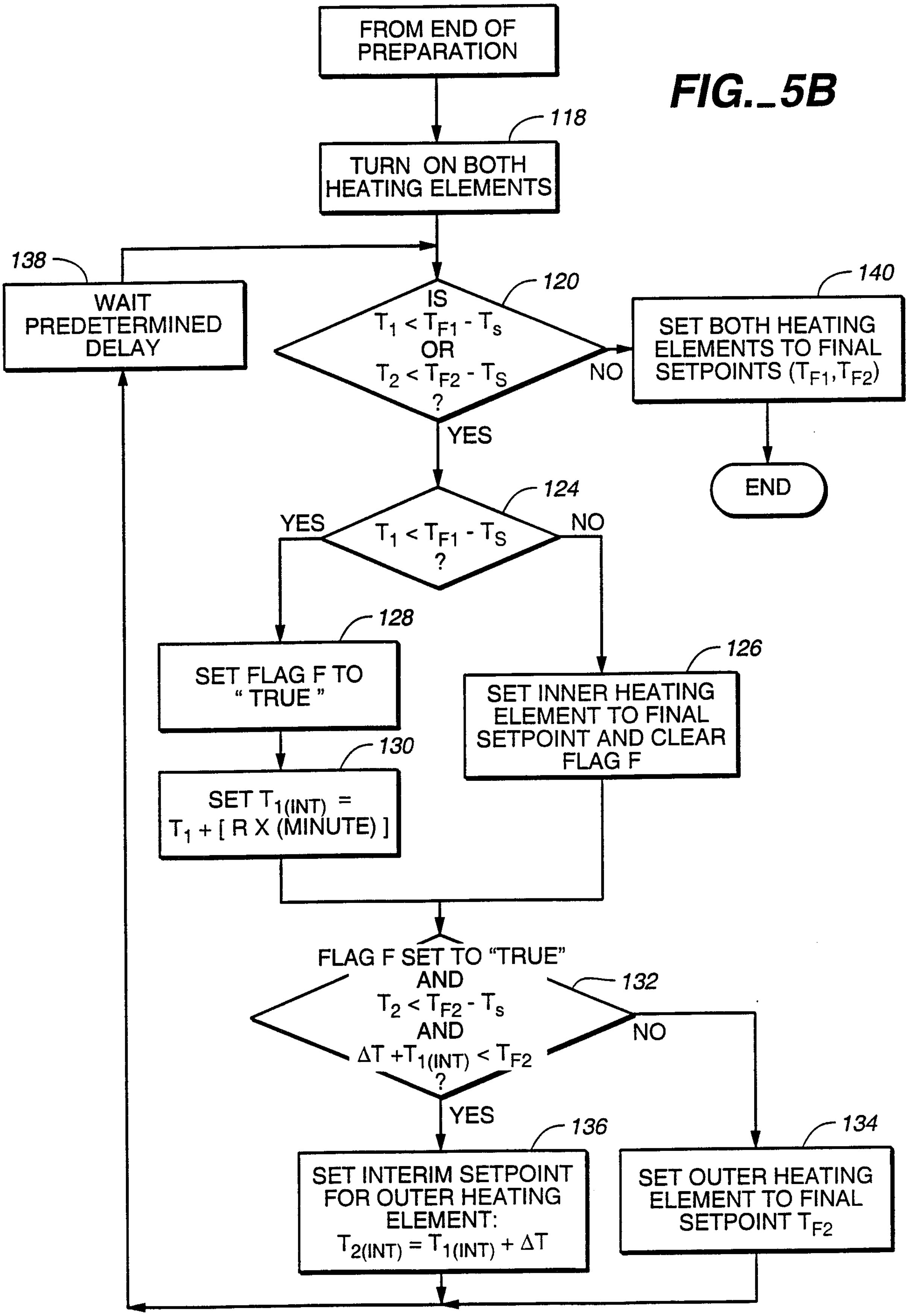

FROM END OF PREPARATION
118
TURN ON BOTH HEATING ELEMENTS
138
WAIT PREDETERMINED DELAY
120
IS $T_1 < T_{F1} - T_s$ OR $T_2 < T_{F2} - T_S$?
NO
140
SET BOTH HEATING ELEMENTS TO FINAL SETPOINTS (T_{F1},T_{F2})
END
YES
124
YES
$T_1 < T_{F1} - T_S$?
NO
128
SET FLAG F TO " TRUE "
126
SET INNER HEATING ELEMENT TO FINAL SETPOINT AND CLEAR FLAG F
130
SET $T_{1(INT)}$ = T_1 + [R X (MINUTE)]
FLAG F SET TO "TRUE" AND $T_2 < T_{F2} - T_s$ AND $\Delta T + T_{1(INT)} < T_{F2}$?
132
NO
YES
136
SET INTERIM SETPOINT FOR OUTER HEATING ELEMENT: $T_{2(INT)} = T_{1(INT)} + \Delta T$
134
SET OUTER HEATING ELEMENT TO FINAL SETPOINT T_{F2}

FIG._5B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/15852

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C03B29/02 C23C16/50 H01L21/314 C23C16/30 G05D23/19

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C03B C23C H01L G05D

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 661 732 A (APPLIED MATERIALS) 5 July 1995 (1995-07-05) page 4, line 7 - line 54; figure 1	1,15
A	EP 0 798 773 A (SUMITOMOELECTRIC INDUSTRIES) 1 October 1997 (1997-10-01) column 9, line 45 -column 10, line 23; figures 8,9	1,15
A	EP 0 823 492 A (CONCEPT SYSTEMS DESIGN & ADVACED ENERGY INDUSTRIES) 11 February 1998 (1998-02-11) column 8, line 56 -column 10, line 9; figures 1-4	1,15
A	US 4 886 954 A (C.-T. YU ET AL) 12 December 1989 (1989-12-12) claim 1; figures 4-6	1,15

-/--

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

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 October 1999	02/11/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Goetz, P

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/15852

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 061 870 A (Y. MIZUSHINA) 6 December 1977 (1977-12-06) column 3, line 38 - line 63; figure 2 -----	1,15

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/15852

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 661732	A	05-07-1995	JP	8003749	A	09-01-1996
			US	5928732	A	27-07-1999
EP 0798773	A	01-10-1997	JP	9321105	A	12-12-1997
EP 823492	A	11-02-1998	US	5653808	A	05-08-1997
			CN	1183020	A	27-05-1998
			CN	1176317	A	18-03-1998
			EP	0823491	A	11-02-1998
			JP	11003863	A	06-01-1999
			JP	10183353	A	14-07-1998
US 4886954	A	12-12-1989	NONE			
US 4061870	A	06-12-1977	JP	51015835	A	07-02-1976