

Methods of Fault Detection for Multiplexed Heater Array

Background

[0001] With each successive semiconductor technology generation, substrate diameters tend to increase and transistor sizes decrease, resulting in the need for an ever higher degree of accuracy and repeatability in substrate processing. Semiconductor substrate materials, such as silicon substrates, are processed by techniques which include the use of vacuum chambers. These techniques include non-plasma applications such as electron beam deposition, as well as plasma applications, such as sputter deposition, plasma-enhanced chemical vapor deposition (PECVD), resist strip, and plasma etch.

[0002] Plasma processing systems available today are among those semiconductor fabrication tools which are subject to an increasing need for improved accuracy and repeatability. One metric for plasma processing systems is improved uniformity, which includes uniformity of process results on a semiconductor substrate surface as well as uniformity of process results of a succession of substrates processed with nominally the same input parameters. Continuous improvement of on-substrate uniformity is desirable. Among other things, this calls for plasma chambers with improved uniformity, consistency and self diagnostics.

[0003] A heating plate for a substrate support assembly in a semiconductor processing apparatus with multiple independently controllable planar heater zones is disclosed in commonly-owned U.S. Patent Application Serial No. 12/582,991, the disclosure of which is hereby incorporated by reference. This heating plate comprises a scalable multiplexing layout scheme of the planar heater zones and the power supply and power return lines. By tuning the power of the planar heater zones, the temperature profile during processing can be shaped both radially and azimuthally. Although this heating plate is primarily described for a plasma processing apparatus, this heating plate can also be used in other semiconductor processing apparatuses that do not use plasma. To prevent overheating in the heating zones, a fault detection system would be desirable.

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Summary of the Invention

- [0004] Described herein is a method of fault detection for a multi-zone heating plate in a substrate support assembly used to support a semiconductor substrate in a semiconductor processing apparatus, the heating plate comprising a plurality of planar heater zones, a plurality of power supply lines and a plurality of power return lines, wherein each planar heater zone is connected to one of the power supply lines and one of the power return lines, and no two planar heater zones share the same pair of power supply line and power return line; the method comprising:
- (a) obtaining a measured total heating power of one or more planar heater zones;
- (b) comparing the measured total heating power to a pre-established total heating power of the one or more planar heater zones; (c) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal.

Brief Description of Drawings

- [0005] Fig. 1 is a schematic of the cross-sectional view of a substrate support assembly in which a heating plate with an array of planar heater zones is incorporated, the substrate support assembly also comprising an electrostatic chuck (ESC).
- [0006] Fig. 2 illustrates the electrical connection from power supply lines and power return lines to an array of planar heater zones in the heating plate.
- [0007] Fig. 3 is a schematic of an exemplary plasma processing chamber, which can include the substrate support assembly of Fig. 1.
- [0008] Fig. 4 shows electrical connections of voltmeters and ammeters to the heating plate according to one embodiment.
- [0009] Fig. 5 shows electrical connections of voltmeters and ammeters to the heating plate according to another embodiment.
- [0010] Fig. 6 shows electrical connections of voltmeters and ammeters to the heating plate according to yet another embodiment.
- [0011] Fig. 7 shows electrical connections of a voltmeter, an ammeter and two multiplexers to the heating plate.

Detailed Description

[0012] Radial and azimuthal substrate temperature control in a semiconductor processing apparatus to achieve desired critical dimension (CD) uniformity on the substrate is becoming more demanding. Even a small variation of temperature may affect CD to an unacceptable degree, especially as CD approaches sub-100nm in semiconductor fabrication processes.

[0013] A substrate support assembly may be configured for a variety of functions during processing, such as supporting the substrate, tuning the substrate temperature, and supplying radio frequency power. The substrate support assembly can comprise an electrostatic chuck (ESC) useful for electrostatically clamping a substrate onto the substrate support assembly during processing. The ESC may be a tunable ESC (T-ESC). A T-ESC is described in commonly assigned U.S. Patent Nos. 6,847,014 and 6,921,724, which are hereby incorporated by reference. The substrate support assembly may comprise a ceramic substrate holder, a fluid-cooled heat sink (hereafter referred to as cooling plate) and a plurality of concentric planar heater zones to realize step by step and radial temperature control. Typically, the cooling plate is maintained between -20 °C and 80 °C. The heaters are located on the cooling plate with a layer of thermal insulator in between. The heaters can maintain the support surface of the substrate support assembly at temperatures about 0 °C to 90 °C above the cooling plate temperature. By changing the heater power within the plurality of planar heater zones, the substrate support temperature profile can be changed between center hot, center cold, and uniform. Further, the mean substrate support temperature can be changed step by step within the operating range of 0 to 90 °C above the cooling plate temperature. A small azimuthal temperature variation poses increasingly greater challenges as CD decreases with the advance of semiconductor technology.

[0014] Controlling temperature is not an easy task for several reasons. First, many factors can affect heat transfer, such as the locations of heat sources and heat sinks, the movement, materials and shapes of the media. Second, heat transfer is a dynamic process. Unless the system in question is in heat equilibrium, heat transfer will occur and the temperature profile and heat transfer will change with time. Third, non-equilibrium phenomena, such as plasma, which of course is always

present in plasma processing, make theoretical prediction of the heat transfer behavior of any practical plasma processing apparatus very difficult.

- [0015] The substrate temperature profile in a plasma processing apparatus is affected by many factors, such as the plasma density profile, the RF power profile and the detailed structure of the various heating the cooling elements in the chuck, hence the substrate temperature profile is often not uniform and difficult to control with a small number of heating or cooling elements. This deficiency translates to non-uniformity in the processing rate across the whole substrate and non-uniformity in the critical dimension of the device dies on the substrate.
- [0016] In light of the complex nature of temperature control, it would be advantageous to incorporate multiple independently controllable planar heater zones in the substrate support assembly to enable the apparatus to actively create and maintain the desired spatial and temporal temperature profile, and to compensate for other adverse factors that affect CD uniformity.
- [0017] A heating plate for a substrate support assembly in a semiconductor processing apparatus with multiple independently controllable planar heater zones is disclosed in commonly-owned U.S. Published Patent Application No. 2011/0092072, the disclosure of which is hereby incorporated by reference. This heating plate comprises a scalable multiplexing layout scheme of the planar heater zones and the power supply and power return lines. By tuning the power of the planar heater zones, the temperature profile during processing can be shaped both radially and azimuthally. Although this heating plate is primarily described for a plasma processing apparatus, this heating plate can also be used in other semiconductor processing apparatuses that do not use plasma.
- [0018] The planar heater zones in this heating plate are preferably arranged in a defined pattern, for example, a rectangular grid, a hexagonal grid, a polar array, concentric rings or any desired pattern. Each planar heater zone may be of any suitable size and may have one or more heater elements. All heater elements in a planar heater zone are turned on or off together. To minimize the number of electrical connections, power supply lines and power return lines are arranged such that each power supply line is connected to a different group of planar heater zones, and each power return line is connected to a different group of planar heater zones

wherein each planar heater zone is in one of the groups connected to a particular power supply line and one of the groups connected to a particular power return line. No two planar heater zones are connected to the same pair of power supply and power return lines. Thus, a planar heater zone can be activated by directing
5 electrical current through a pair of power supply and power return lines to which this particular planar heater zone is connected. The power of the heater elements is preferably smaller than 20W, more preferably 5 to 10 W. The heater elements may be resistive heaters, such as polyimide heaters, silicone rubber heaters, mica heaters, metal heaters (e.g. W, Ni/Cr alloy, Mo or Ta), ceramic heaters (e.g. WC),
10 semiconductor heaters or carbon heaters. The heater elements may be screen printed, wire wound or etched foil heaters. In one embodiment, each planar heater zone is not larger than four device dies being manufactured on a semiconductor substrate, or not larger than two device dies being manufactured on a semiconductor substrate, or not larger than one device die being manufactured on a semiconductor
15 substrate, or from 16 to 100 cm² in area, or from 1 to 15 cm² in area, or from 2 to 3 cm² in area to correspond to the device dies on the substrate. The thickness of the heater elements may range from 2 micrometers to 1 millimeter, preferably 5-80 micrometers. To allow space between planar heater zones and/or power supply and power return lines, the total area of the planar heater zones may be up to 90% of the
20 area of the upper surface of the substrate support assembly, e.g. 50-90% of the area. The power supply lines or the power return lines (power lines, collectively) may be arranged in gaps ranging from 1 to 10 mm between the planar heater zones, or in separate planes separated from the planar heater zones plane by electrically insulating layers. The power supply lines and the power return lines are preferably
25 made as wide as the space allows, in order to carry large current and reduce Joule heating. In one embodiment, in which the power lines are in the same plane as the planar heater zones, the width of the power lines is preferably between 0.3 mm and 2 mm. In another embodiment, in which the power lines are on different planes than the planar heater zones, the width of the power lines can be as large as the planar
30 heater zones, e.g. for a 300 mm chuck, the width can be 1 to 2 inches. The materials of the power lines may be the same as or different from the materials of the heater

elements. Preferably, the materials of the power lines are materials with low resistivity, such as Cu, Al, W, Inconel[®] or Mo.

[0019] Fig. 1 shows a substrate support assembly comprising one embodiment of the heating plate having an array of planar heater zones 101 incorporated in two electrically insulating layers 104A and 104B. The electrically insulating layers may be a polymer material, an inorganic material, a ceramic such as silicon oxide, alumina, yttria, aluminum nitride or other suitable material. The substrate support assembly further comprises (a) an ESC having a ceramic layer 103 (electrostatic clamping layer) in which an electrode 102 (e.g. monopolar or bipolar) is embedded to electrostatically clamp a substrate to the surface of the ceramic layer 103 with a DC voltage, (b) a thermal barrier layer 107, (c) a cooling plate 105 containing channels 106 for coolant flow.

[0020] As shown in Fig. 2, each of the planar heater zones 101 is connected to one of the power supply lines 201 and one of the power return lines 202. No two planar heater zones 101 share the same pair of power supply line 201 and power return line 202. By suitable electrical switching arrangements, it is possible to connect a pair of power supply 201 and power return 202 lines to a power supply (not shown), whereby only the planar heater zone connected to this pair of lines is turned on. The time-averaged heating power of each planar heater zone can be individually tuned by time-domain multiplexing. In order to prevent crosstalk between different planar heater zones, a diode 250 is serially connected between each planar heater zone 101 and the power supply line 201 connected thereto (as shown in Fig. 2), or between each planar heater zone 101 and the power return line 202 connected thereto (not shown) such that the diode 250 does not allow electrical current flow in a direction from the power return line 201 through the planar heater zone 101 to the power supply line 201. The diode 250 is physically located in or adjacent the planar heater zone.

[0021] A substrate support assembly can comprise an embodiment of the heating plate, wherein each planar heater zone of the heating plate is of similar size to or smaller than a single device die or group of device dies on the substrate so that the substrate temperature, and consequently the plasma etching process, can be controlled for each device die position to maximize the yield of devices from the

substrate. The heating plate can include 10-100, 100-200, 200-300 or more planar heating zones. The scalable architecture of the heating plate can readily accommodate the number of planar heater zones required for die-by-die substrate temperature control (typically more than 100 dies on a substrate of 300-mm diameter and thus 100 or more heater zones) with minimal number of power supply lines, power return lines, and feedthroughs in the cooling plate, thus reduces disturbance to the substrate temperature, the cost of manufacturing and complexity of the substrate support assembly. Although not shown, the substrate support assembly can comprise features such as lift pins for lifting the substrate, helium back cooling, temperature sensors for providing temperature feedback signals, voltage and current sensors for providing heating power feedback signals, power feed for heaters and/or clamp electrode, and/or RF filters.

[0022] As an overview of how a plasma processing chamber operates, Fig. 3 shows a schematic of a plasma processing chamber comprising a chamber 713 in which an upper showerhead electrode 703 and a substrate support assembly 704 are disposed. A substrate (e.g., 300 mm wafer) 712 is loaded through a loading port 711 onto the substrate support assembly 704. A gas line 709 supplies process gas to the upper showerhead electrode 703 which delivers the process gas into the chamber. A gas source 708 (e.g. a mass flow controller "MFC" supplying a suitable gas mixture) is connected to the gas line 709. A RF power source 702 is connected to the upper showerhead electrode 703. In operation, the chamber is evacuated by a vacuum pump 710 and the RF power is capacitively coupled between the upper showerhead electrode 703 and a lower electrode in the substrate support assembly 704 to energize the process gas into a plasma in the space between the substrate 712 and the upper showerhead electrode 703. The plasma can be used to etch device die features into layers on the substrate 712. The substrate support assembly 704 may have heaters incorporated therein as disclosed above. It should be appreciated that while the detailed design of the plasma processing chamber may vary, RF power is coupled to the plasma through the substrate support assembly 704.

[0023] Electrical power supplied to each planar heater zone 101 can be adjusted based on the actual temperature thereof in order to achieve a desired substrate support temperature profile. The actual temperature at each planar heater zone 101

can be monitored by measuring a reverse saturation current of the diode 250 connected thereto. The actual temperature at each planar heater zone 101 can also be monitored by thermocouples or fluoro-optic temperature sensors at each planar heater zone.

- 5 **[0024]** A method of fault detection for the heating plate according to an embodiment, comprises: (a) obtaining a measured total heating power of one or more planar heater zones; (b) comparing the measured total heating power to a pre-established total heating power of the one or more planar heater zones; (c) if the measured total heating power deviates from the pre-established total heating power
10 by a pre-determined margin, triggering an alarm signal. The pre-determined margin can be, for example, $\pm 20\%$, $\pm 10\%$, $\pm 5\%$, or $\pm 1\%$ of the pre-established total heating power. During processing of a semiconductor substrate, the alarm signal can be used to trigger a recalibration test or a power adjustment to the heating zone triggering the alarm.
- 15 **[0025]** A measured heating power of each of the one or more planar heater zones in step (a) can be obtained by measuring a voltage V across that planar heater zone, measuring a current I flowing through that planar heater zone and multiplying V by I . The measured total heating power in step (a) is a sum of the measured heating power of each of the one or more planar heater zones. The voltage measurement can
20 be carried out with a voltmeter or other suitable voltage measuring device and the current measurement can be obtained using an ammeter or other suitable current measuring device.

- [0026]** As shown in Fig. 4, the heating plate can have a voltmeter 520 (or other suitable voltage measuring device) connected between the power supply line 201
25 and return line 202 connected to a heating zone 101, and an ammeter 530 (or other suitable current measuring device) is serially connected between each planar heater zone 101 and the power return line 202 or the power supply line 201 connected thereto. A processor 5000 (e.g. a computer, a micro-controller, etc.) is operable to take a voltage reading from each voltmeter 520 and take a current reading from each
30 ammeter 530. In a heating plate with an N -by- M array of heater zones, N power supply lines and M power return lines, $N \times M$ ammeters and $N \times M$ voltmeters are needed. A method of fault detection comprises: (a) while a planar heater zone is

- powered, obtaining a measured heating power of the planar heater zone by measuring a voltage V across the planar heater zone, preferably using the voltmeter 520 connected thereto, and measuring a current I flowing through the planar heater zone, preferably using the ammeter 530 connected thereto, and multiplying V by I ;
- 5 (b) comparing the measured heating power of the planar heater zone to a pre-established heating power of the planar heater zone; (c) if the measured heating power deviates from the pre-established heating power by a pre-determined margin, triggering an alarm signal.
- [0027] Alternatively, as shown in Fig. 5, a voltmeter 520 is connected to each
- 10 power supply line 201; an ammeter 530 is serially connected to each power return line 202 such that when any power return line 202 is connected to an electrical ground, the ammeter 530 is between the power return line 202 and the electrical ground. A processor 5000 is operable to take a voltage reading from each voltmeter 520 and take a current reading from each ammeter 530. In a heating plate with an
- 15 N -by- M array of heater zones, N power supply lines and M power return lines, N voltmeters and M ammeters are needed. A method of fault detection comprises:
- (a) while one or more power supply lines 201 are connected to a power source, and at least one power return line 202 is connected to an electrical ground, obtaining a measured total heating power of the planar heater zones connected to the one or
- 20 more power supply lines 201 and the at least one power return line 202, by measuring a voltage V on the one or more power supply lines 201, preferably using at least one of the voltmeters 520 connected thereto, and measuring a total current I carried by at least one power return line 202, preferably using the ammeter 530 connected thereto, and multiplying V by I ; (b) comparing the measured total heating
- 25 power to a pre-established total heating power calculated by summing a pre-established heating power of each of the planar heater zones connected to the one or more power supply lines 201 and the at least one power return line 202; (c) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal.
- 30 [0028] Alternatively, as shown in Fig. 6, a voltmeter 520 is connected to each power supply line 201; an ammeter 530 is serially connected to each power supply line 201 such that when any power supply line 201 is connected to a power source,

all electrical current carried by that power supply line 201 flows through the ammeter 530 connected thereto before flowing into any planar heater zones 101. A processor 5000 is operable to take a voltage reading from each voltmeter 520 and take a current reading from each ammeter 530. In a heating plate with an N -by- M array of heater zones, N power supply lines and M power return lines, N voltmeters and N ammeters are needed. A method of fault detection comprises: (a) while one or more power return lines 202 are connected to an electrical ground, and at least one power supply line 201 is connected to a power source, obtaining a measured total heating power of the planar heater zones connected to the one or more power return lines 202 and the at least one power supply line 201, by measuring a voltage V on the at least one power supply line 201, preferably using the voltmeter 520 connected thereto, measuring a current I on at least one power supply line 201, preferably using the ammeter 530 connected thereto, and multiplying V by I ; (b) comparing the measured total heating power to a pre-established total heating power calculated by summing a pre-established heating power of each of the planar heater zones connected to the one or more power return lines 202 and the at least one power supply line 201; (c) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal.

[0029] Alternatively as shown in Fig. 7, a multiplexer 1000 is configured to connect each power return line 202 selectively to an electrical ground through an ammeter 530, an electrically isolated terminal, independent of the other power return lines; a multiplexer 2000 is configured to selectively connect each power supply line 201 to an electrically isolated terminal, independent of the other power supply lines. A processor 5000 is operable to take a voltage reading from the voltmeter 520 and take a current reading from the ammeter 530, and controls the multiplexers 1000 and 2000. In a heating plate with an N -by- M array of heater zones, N power supply lines and M power return lines, only one voltmeter and one ammeter are needed. A method of fault detection comprises: (a) while all power return lines 202 are connected to the electrical ground through the ammeter 530 and only the i -th power supply line 201 is connected to the power source, obtaining a measured total heating power of all the planar heater zones connected to the i -th power supply line 201, by

measuring a voltage V on the i -th power supply line 201, preferably using the voltmeter 520, measuring a total current I on all the power return lines 202, preferably using the ammeter 530, and multiplying V by I ; (b) comparing the total heating power to a pre-established total heating power calculated by summing a pre-established heating power of each of the planar heater zones connected to the i -th power supply line 201; (c) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal; (d) while all power supply lines 201 are connected to the power source and only the j -th power return line 202 is connected to the electrical ground, obtaining a total heating power of all the planar heater zones connected to the j -th power return line 202, measuring a voltage V on all the power supply lines 201, preferably using the voltmeter 520, measuring a current I on the j -th power return line 202, preferably using the ammeter 530, and multiplying V by I ; (e) comparing the measured total heating power to a pre-established total heating power calculated by summing a pre-established heating power of each of the planar heater zones connected to the j -th power return line; (f) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal. This method can further identify which planar heater zone is in a fault condition: if an alarm signal is triggered when only the i -th power supply line 201 is connected to the power source and all the power return lines 202 are connected to the electrical ground, and when only the j -th power return line 202 is connected to the electrical ground and all the power supply lines 201 are connected to the power source, the planar heater zone connected to both the i -th power supply line 201 and the j -th power return line 202 is in a fault condition.

[0030] A measurement error can be rectified by subtracting voltage drop that is not on a planar heater zone, such as voltage drop on power supply lines 201, power return lines 202 and/or the diodes 250 from a voltage V measured on a power supply line 201.

[0031] While methods of fault detection for a heating plate for a substrate support assembly in a semiconductor processing apparatus with multiple independently controllable planar heater zones have been described in detail with reference to specific embodiments thereof, it will be apparent to those skilled in the art that

various changes and modifications can be made, and equivalents employed, without departing from the scope of the appended claims.

I Claim:

1. A method of fault detection for a multi-zone heating plate in a substrate support assembly used to support a semiconductor substrate in a semiconductor processing apparatus, the heating plate comprising a plurality of planar heater zones,
5 a plurality of power supply lines and a plurality of power return lines, wherein each planar heater zone is connected to one of the power supply lines and one of the power return lines, and no two planar heater zones share the same pair of power supply line and power return line; the method comprising:
 - (a) obtaining a measured total heating power of one or more planar heater
10 zones;
 - (b) comparing the measured total heating power to a pre-established total heating power of the one or more planar heater zones;
 - (c) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal.
- 15 2. The method of Claim 1, wherein the pre-determined margin is $\pm 20\%$, $\pm 10\%$, $\pm 5\%$, or $\pm 1\%$ of the pre-established total heating power.
- 20 3. The method of Claim 1, wherein the measured total heating power is obtained by measuring a voltage V across each of the one or more planar heater zones, measuring a current I flowing through each of the one or more planar heater zones, multiplying V by I , and adding $V \cdot I$ of each of the one or more planar heater zones.
- 25 4. The method of Claim 3, wherein the voltage V is measured using a voltmeter connected between one of the power supply lines and one of the power return lines, and the current I is measured using an ammeter connected between one of the power return lines and ground.
- 30 5. The method of Claim 1, wherein:
 - while one or more power supply lines are connected to a power source, and at least one power return line is connected to an electrical ground, the measured total

- heating power of the planar heater zones connected to the one or more power supply lines and the at least one power return line is obtained by measuring a voltage V on the one or more power supply lines, and measuring a total current I carried by the at least one power return line, and multiplying V by I ; and
- 5 the pre-established total heating power is calculated by summing a pre-established heating power of each of the planar heater zones connected to the one or more power supply lines and the at least one power return line.
6. The method of Claim 1, wherein:
- 10 while one or more power return lines are connected to an electrical ground, and at least one power supply line is connected to a power source, the measured total heating power of the planar heater zones connected to the one or more power return lines and the at least one power supply line is obtained by measuring a voltage V on the at least one power supply line, measuring a current I on the at least one power
- 15 supply line, and multiplying V by I ; and
- the pre-established total heating power is calculated by summing a pre-established heating power of each of the planar heater zones connected to the one or more power return lines and the at least one power supply line.
- 20 7. The method of Claim 5, wherein the voltage V on the one or more power supply lines is corrected by subtracting voltage drop that is not on a planar heater zone.
8. The method of Claim 6, wherein the voltage V on the at least one power
- 25 supply line is corrected by subtracting voltage drop that is not on a planar heater zone.
9. A method of fault detection for a multi-zone heating plate in a substrate support assembly used to support a semiconductor substrate in a semiconductor
- 30 processing apparatus, the heating plate comprising a plurality of planar heater zones, a plurality of power supply lines and a plurality of power return lines, wherein each planar heater zone is connected to one of the power supply lines and one of the

power return lines, and no two planar heater zones share the same pair of power supply line and power return line; the method comprising:

- (a) while all power return lines are connected to the electrical ground through the ammeter and only the i -th power supply line is connected to the power source,
5 obtaining a measured total heating power of all the planar heater zones connected to the i -th power supply line, by measuring a voltage V on the i -th power supply line, measuring a total current I on all the power return lines, and multiplying V by I ;
- (b) comparing the total heating power to a pre-established total heating power calculated by summing a pre-established heating power of each of the planar
10 heater zones connected to the i -th power supply line;
- (c) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal;
- (d) while all power supply lines are connected to the power source and only the j -th power return line is connected to the electrical ground, obtaining a total
15 heating power of all the planar heater zones connected to the j -th power return line, measuring a voltage V on all the power supply lines, measuring a current I on the j -th power return line, and multiplying V by I ;
- (e) comparing the measured total heating power to a pre-established total heating power calculated by summing a pre-established heating power of each of the planar heater zones connected to the j -th power return line;
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- (f) if the measured total heating power deviates from the pre-established total heating power by a pre-determined margin, triggering an alarm signal.

10. The method Claim 9, further comprising identifying that the planar heater
25 zone connected to both the i -th power supply line and the j -th power return line is in a fault condition, if an alarm signal is triggered when only the i -th power supply line is connected to the power source and all the power return lines are connected to the electrical ground, and when only the j -th power return line is connected to the electrical ground and all the power supply lines are connected to the power source,
30 the planar heater zone connected to both the i -th power supply line and the j -th power return line is in a fault condition.

11. The method of Claim 9, wherein the voltage V on all the power supply lines and the voltage V on the i -th power supply line are corrected by subtracting voltage drop that is not on a planar heater zone.