

System and Method for Temperature Measurement, and Calibration Method

The present invention relates to a system and a method for temperature measurement in a process chamber of a high-
5 temperature furnace for workpiece processing, more particularly semiconductor processing, and to a calibration method for at least one temperature measurement means of a high-temperature furnace.

10 Workpieces, particularly semiconductor wafers, are typically treated using high-temperature furnaces possessing a heatable process chamber also referred to as the "tube". The workpieces are arranged in the process chamber with the aid of a so-called "boat", where they are then heated to temperatures of
15 more than 2000°C, optionally in a vacuum or a specified gas atmosphere. This enables the implementation of processes such as diffusion, dry or wet oxidation, or annealing, for example with hydrogen H₂, argon Ar or nitrogen N₂.

20 In order to allow such processes to be precisely initiated and controlled, it is desirable for the temperature in the process chamber to be monitored with very high accuracy. The arranging of temperature sensors within the process chamber is generally not an option in regular operation, owing to the high
25 temperatures, to the cost and complexity associated with connection in the process chamber, which may have gas-tight sealing, and to potential contamination of the process chamber with sensor materials; consequently, temperature measurement means are typically provided outside the process chamber, for
30 indirect determination of temperature. Such external temperature measurement means, in the form for example of pyrometers or thermocouples, measure the temperature of the

process chamber wall or of a process chamber insulation at an arbitrary location from the outside – that is, they measure the external temperature of the process chamber, from which the internal temperature of the process chamber is derived. In order to do this, however, the external temperature measurement means must be calibrated correspondingly beforehand.

The calibration of external temperature measurement means is typically carried out with the aid of a thermocouple, which is inserted into the process chamber through an opening that is closed in regular operation. One problem associated with this is that, especially at high temperatures of 1500°C or more, for example, thermocouples may generate measurement errors, considerable in some cases, and/or may contain substances which are volatile at these temperatures and possibly contaminate the process chamber. Above 1700°C, the likelihood of failure may also be greater.

Against this background, it is an object of the present invention to improve temperature measurement in a process chamber and the calibration of external temperature measurement means, more particularly to make them more precise and/or to enable them reliably even at temperatures above 1700°C.

This object is achieved by a system and a method for temperature determination in a process chamber of a high-temperature furnace for workpiece processing and by a calibration method for at least one temperature measurement means of a high-temperature furnace, in accordance with the independent claims.

Preferred embodiments are subjects of the dependent claims and of the description hereinbelow.

5 A system for temperature determination in a process chamber of a high-temperature furnace for workpiece processing, more particularly semiconductor processing, according to a first aspect of the invention comprises a heatable process chamber, particularly for accommodating workpieces that are to be processed. The process chamber comprises an opening. Provided
10 in accordance with the invention is a measuring device which is arranged in front of the opening, in particular outside the process chamber, i.e. exclusively, and is intended for contactlessly determining a temperature within the process chamber through the - optionally sealed - opening.

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A measuring device of this kind in the sense of the present invention is preferably a device configured for detecting electromagnetic radiation, especially thermal or infrared radiation. The measuring device may be embodied for example as
20 a pyrometer. The measuring device is able to determine a temperature of a measurement target by detecting the electromagnetic radiation irradiated by the measurement target, more particularly by a region of its surface.

25 In the process chamber there is usefully a process volume defined in which workpieces intended for processing can be arranged.

An opening of the process chamber in the sense of the
30 invention is preferably a portal to the process volume in the process chamber, via which electromagnetic radiation from at least one wavelength range, for example in the infrared range, is able to enter the process chamber and/or emerge from the process chamber. If this opening can be sealed, more

particularly hermetically, e.g. in gas-tight manner, by a seal, it usefully comprises a window. In that case the window is preferably pervious to electromagnetic radiation from at least one wavelength range, for example in the infrared range, to allow a temperature in the process chamber to be measured contactlessly from outside. The window in this sense defines the portal to the process volume.

To be able to prevent contamination of the process volume in the process chamber through the opening, as an alternative to a seal, it is also conceivable for the process volume to be protected by means of a protective gas, argon for example, which is introduced into the process volume. In that case a temperature in the process chamber can also be determined contactlessly through a protective gas, as the protective gas usefully transmits electromagnetic radiation.

One aspect of the invention is based on the approach of performing contactless, radiation-based temperature measurement in a process chamber of a high-temperature furnace for workpiece processing, more particularly semiconductor processing. For this purpose, a corresponding measuring device, a pyrometer for example, is arranged in front of an opening of the process chamber. A temperature, more particularly the surface temperature of a measurement target, within the process chamber can be determined by means of this measuring device through the optionally sealed opening, for instance through a window in a seal or through a protective gas atmosphere. It is consequently possible for the temperature to be determined in situ from outside the process chamber. The provision of a measuring device in front of the process chamber window enables, in particular, in situ reference to an arbitrary temperature scale. In particular,

temperatures above 1700°C can also be reliably detected in situ.

Causing problems for such contactless temperature

5 determination through the process chamber opening may be the resultant geometric restrictions on the field of view of the measuring device. In particular, an insulation means serving for thermal insulation of the opening region, for instance of a process chamber seal for a process volume in the process
10 chamber, may hinder contactless determination of the temperature within the process volume, as measurement has to take place not only through the opening but also through a narrow channel in the insulation means that adjoins the opening and opens out into the process volume.

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In one preferred embodiment, therefore, a manipulation device for aligning a detection region of the measuring device is provided. The manipulation device may be configured, for example, to position the detection region of the measuring
20 device relative to the process chamber and any components arranged therein, i.e. to change the position of the detection region in particular relative to a longitudinal axis of the process chamber. This makes it possible to prevent parts of the opening or its seal and/or parts of the insulation means,
25 more particularly a part of the channel wall, from lying within the detection region. In particular, the detection region may thus be aligned to a measurement target in the process volume for which the temperature is to be ascertained.

30 A detection region in the sense of the invention is preferably a region in which the measuring device detects a temperature and/or the corresponding electromagnetic radiation.

Alignment of the detection region may be achieved, for example, through manipulation of the beam path of the electromagnetic radiation detected by the measuring device. It is therefore useful for the manipulation device to be embodied
5 as an optical system or at least to comprise an optical system. The optical system allows electromagnetic radiation from the process volume in the process chamber, through the channel in the insulation means and the opening, to be imaged onto the measuring device, more particularly onto a
10 corresponding sensor of the measuring device.

Alternatively or additionally, the detection region may be aligned in a particularly simple, low-cost and low-complexity manner through manipulation of the arrangement of the
15 measuring device in front of the process chamber opening, i.e. by changing the position and/or alignment of the measuring device relative to the process chamber. The manipulating device therefore usefully comprises a positioning device, for example an actuator, for moving the measuring device relative
20 to the process chamber. Possibilities resulting from the movement by means of the positioning device here are, in particular, a (re-)positioning of the measuring device, for example to specified coordinates, and a (re-)alignment of the measuring device, for example into a specified direction.
25 Relative to an optical system, the positioning device has the advantage that it can be realized at lighter weight and is more robust.

To allow the measuring device to be optimally positioned and
30 aligned, i.e. to make it possible to prevent the detection region of the measuring device being aligned to a measurement target and hence, for example, to prevent detection of electromagnetic radiation originating from the channel surface of the channel in the insulation means, the positioning device

is preferably configured for moving the measuring device in at least two degrees of freedom. With particular preference, the positioning device is configured i) for positioning the measuring device in respect of at least two degrees of translation freedom, more particularly for the translation of the measuring device in a plane parallel to the opening, and ii) for aligning the measuring device in respect of two degrees of rotational freedom, more particularly for tilting the measuring device relative to a longitudinal axis of the process chamber.

After such alignment of the detection region of the measuring device, the temperature determined by means of the measuring device can be used for calibrating external temperature measurement means, more particularly even outside the temperature range detectable by means of conventional thermocouples. For example, the temperature within the process chamber, determined precisely by means of the measuring device on the basis of its alignment beforehand, may be assigned to a measured value of at least one (external) temperature measurement means. A controlling device may be provided for this purpose.

Because the electromagnetic radiation detected by the measuring device may be influenced on transmission through the opening, for instance the window in the seal, it is useful likewise to calibrate the measuring device, in particular prior to the calibration of the external temperature measurement means. For this purpose, there is preferably at least one temperature reference means provided which can be arranged within the process chamber, being more particularly embodied for mounting by a boat which can be arranged in the process chamber. The temperature reference means is usefully embodied in such a way that determination of its temperature

over a temperature range by means of the measuring device provides information on the temperature actually prevailing within the process chamber. For example, the temperature reference means may be embodied in such a way that a
5 temperature profile of the temperature reference means, obtained by substantially continuous determination of the temperature, for steadily rising internal temperature in the process chamber, comprises a characteristic feature associated with a specified temperature.

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For this purpose, the temperature reference means may comprise a melt sample, arranged for example on a carrier and having a predefined melting temperature. In that case it is useful for the melt sample to be held by the carrier in such a way that
15 on arrangement of the carrier, held in particular by a boat, in the process chamber, a temperature of the melt sample can be determined by means of the measuring device through the opening. Accordingly, the detection region of the measuring device can be usefully aligned to the melt sample if the
20 carrier is arranged in the process chamber.

If the temperature in the process chamber is raised above the melting temperature of the melt sample, the temperature of the melt sample, because of the enthalpy of fusion, stagnates at
25 the melting temperature until said sample is substantially completely molten. The consequent temperature plateau in the temperature profile of the melt sample as determined by means of the measuring device can be assigned to the melting temperature.

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The material of the melt sample may be chosen as a function of the desired temperature at which calibration is to take place. Where calibration is to take place, for example, in the region around 1400°C, it is useful for the melt sample to comprise,

and more particularly to be made of, silicon (the melting temperature of silicon is 1410°C). Where calibration is to take place, conversely, at higher temperatures, for example in the region around 1900°C , it is useful for the melt sample to
5 comprise, and more particularly to be made of, ruthenium carbide (the melting temperature of ruthenium carbide is 1954°C).

The carrier here is usefully made of a material having a
10 higher melting temperature than the melt sample. In practice, a carrier made of graphite has proved to be expedient. The chemical and physical stability of graphite makes it possible to avoid instances of contamination of the process chamber by introduction of the carrier into the process chamber and/or by
15 heating of the carrier in the process chamber. Graphite, moreover, can be purified to a high purity level at relatively low cost and complexity. In principle, however, carriers made of rhenium carbide, platinum carbide, iridium carbide or rhodium carbide are also conceivable. Carriers made of such
20 materials may also have sufficient chemical and physical stability for use in a process chamber of a high-temperature furnace.

In a further preferred embodiment, a position reference means
25 which can be arranged in the process chamber is provided. While the temperature reference means serves usefully to calibrate the measuring device in terms of measuring the correct temperature, the position reference means may serve to optimally align the detection region of the measuring device
30 within the process chamber. For example, the position reference means may be used to ascertain a specified alignment of the detection region. Expressed alternatively, the position reference means may be provided for achieving a desired arrangement of the measuring device outside the process

chamber in front of the opening, more particularly for achieving a desired positioning and/or alignment of the measuring device relative to the process chamber. The position reference means may be used, for example, to achieve an arrangement of the measuring device in front of the opening in which the detection region of the measuring device lies in the region of the longitudinal axis of the process chamber and/or in which the measuring device detects electromagnetic radiation which propagates substantially along the longitudinal axis. The position reference means may therefore help to avoid an adverse effect on the measurement result from the measuring device as a result of the channel wall of the channel in the insulation means.

In principle, the temperature reference means may also be used as a position reference means. On heating of the process chamber, for example to a temperature below the melting temperature of the melt sample, the temperature reference means may heat up to a greater extent than the insulation means, more particularly than the wall of the channel in the insulation means. In that case, for example by responsive movement of the measuring device by means of the positioning device, the detection region of the measuring device can be aligned to what, from the standpoint of the measuring device, is the hottest region in the process chamber, a region defined by a portion of the temperature reference means. In this alignment, it may be assumed that the beam path along which electromagnetic radiation emitted by the temperature reference means propagates to the measuring device extends substantially along the longitudinal axis of the process chamber. The measuring device consequently "sees" only the temperature reference means used as a position reference means.

Alternatively or additionally, however, a (dedicated) position reference means different from the temperature reference means may also be provided or used for achieving a desired alignment of the detection region of the measuring device. It is also possible as a result, optionally, to reference a longitudinal position in the process chamber, i.e. one or more positions along the longitudinal axis of the process chamber, and optionally to move to said positions at a later point in time, for temperature measurement.

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For that purpose, the position reference means comprises at least one perforated plate. The perforated plate is preferably embodied in such a way that on arrangement in the process chamber, a temperature of the perforated plate is determinable in a reference region at the edge of the perforation by means of the measuring device through the opening. The perforation may be arranged, for example, in the middle of the perforated plate, so that on arrangement of the perforated plate in the process chamber, the perforation is positioned substantially in the region of the longitudinal axis of the process chamber.

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The use of a perforated plate of this kind has the advantage that, on the one hand, the temperature of the perforated plate and hence the internal temperature in the process chamber at the longitudinal position of the perforated plate in the process chamber can be determined by alignment of the detection region of the measuring device to the reference region. On the other hand, it is also possible in principle to determine the temperature at a longitudinal position behind the perforated plate, through the perforation.

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Accordingly, in terms in particular of efficient referencing of multiple longitudinal positions in the process chamber, it is particularly advantageous for the position reference means

to comprise a plurality of reference plates which can be arranged one after another along a longitudinal axis of the process chamber. These reference plates are usefully embodied in such a way that at least in a predetermined sequence and/or
5 alignment of the reference plates arranged in the process chamber relative to one another, the temperature is determinable in a reference region of each temperature reference plate by means of the measuring device through the opening. Expressed alternatively, this plurality of reference
10 plates are preferably embodied in such a way that at least in the predetermined sequence and/or alignment, at most a part of each reference plate is hidden by one or more of the other reference plates. The reference plates may accordingly be embodied, for example, as perforated plates with perforations
15 that line up with one another on arrangement in the process chamber, more particularly in the region of the longitudinal axis of the process chamber. By means of multiple such reference plates, it is possible to determine the temperature in the process chamber at different longitudinal positions by
20 means of the measuring device, without needing to repeatedly reposition an individual position reference means in order to do so.

To be able in particular to perform a temperature measurement
25 at each of the reference plates, when multiple such plates are arranged along the longitudinal axis of the process chamber, it is preferable for the position reference means, more particularly each of the reference plates, to comprise a projection. The projection usefully defines a reference region
30 in which, on arrangement of the position reference means in the process chamber, a temperature of the position reference means is detectable by means of the measuring device through the opening, for instance by the projection filling a subregion of the field of view of the measuring device. A

projection of this kind may be embodied, for example, as a projection protruding into the perforation of a perforated plate.

- 5 Particularly when multiple reference plates embodied as perforated plates are provided, the perforations are usefully embodied as substantially circular perforations having a projection which extends toward the middle of the perforation. These projections preferably each correspond to a circle
- 10 sector or circle segment. Preferentially, the projections of all the reference plates together cover 360° . Where there are three reference plates, for example, the projections therefore each extend over 120° .
- 15 A temperature measurement method for a high-temperature furnace for workpiece processing, more particularly semiconductor processing, in accordance with a second aspect of the invention, comprises steps as follows: i) arranging a measuring device for contactlessly determining a temperature,
- 20 more particularly a surface temperature, in front of a sealable opening of a heatable process chamber, more particularly outside the process chamber, of a high-temperature furnace for workpiece processing, more particularly semiconductor processing; and ii) measuring a
- 25 temperature within the process chamber through the - optionally sealed - opening by means of the measuring device.

This method enables in situ reference to an arbitrary temperature scale. The method can be deployed in principle

30 over a large temperature range, including in particular at temperatures above 1700°C . The method may be used, for example, to calibrate at least one external temperature measurement means of the high-temperature furnace.

In principle, the measuring device used in the method may be arranged in succession in front of process chambers of different high-temperature furnaces. This allows comparison of multiple high-temperature furnaces, for example of their
5 internal temperature for the same heating power or temperature homogeneity, in principle over any desired periods of time, because the measuring device is not exposed to the high temperatures in the process chambers and consequently, in contrast to thermocouples as typically used, there are no
10 associated ageing effects.

To be able to ensure that the measuring device is determining exclusively a temperature in the process chamber, more particularly in the process volume of the process chamber, a
15 detection region of the measuring device is preferably aligned before the temperature is determined. This alignment usefully takes place by means of a manipulating device. The detection region may be aligned for example to a field of view which is defined by the opening, more particularly by the window in the
20 seal, and/or by an insulation means arranged within the process chamber for thermally insulating the region at the process chamber opening. In particular, the detection region may be aligned at the longitudinal axis of the process chamber, so that electromagnetic radiation emitted by a
25 channel wall of the channel through the insulation means is not detected by the measuring device.

Alignment of the measuring region in this way is achievable, for example, by targeted manipulation of an optical system
30 which images electromagnetic radiation from the process chamber, more particularly the process volume, onto the measuring device. For this purpose, in particular, optical properties of the optical system can be changed in a targeted manner, for instance by moving lenses and/or diaphragms

relative to one another, by changing refractive indices of optical elements and/or the like.

Alternatively or additionally, the measuring region may also
5 be aligned in a particularly simple, low-cost and low-complexity manner by actuating a positioning device accordingly. By means of such a positioning device, the measuring device – and hence also its measuring region – are usefully aligned in respect of at least two degrees of
10 freedom. In particular, the measuring device can thereby be positioned in respect of two degrees of translation freedom, for instance by movement in a plane parallel to the opening, and/or aligned in respect of two degrees of rotational freedom, for instance by tilting of the measuring device
15 relative to the longitudinal axis of the process chamber.

To be able to achieve an optimal alignment of the detection region of the measuring device, at which the temperature in the process chamber can be reliably ascertained, by means of
20 the manipulating device, more particularly the positioning device, a position reference means having a reference region is preferably arranged in the process chamber. The position reference means is usefully arranged and/or embodied in such a way that the temperature of the position reference means at
25 least in a reference region of the position reference means can be determined by means of the measuring device through the opening. Usefully, therefore, the position reference means should be arranged in such a way that electromagnetic radiation it emits is detectable through the opening by the
30 measuring device.

The position reference means is heated preferentially by heating of the process chamber, and an alignment of the detection region of the measuring device is determined as a

reference alignment in which the measuring device detects a temperature in the reference region. The reference alignment here is preferably established by the temperature determined in this alignment fulfilling a specified temperature
5 criterion. Such a temperature criterion may result, for example, from the attainment of a temperature maximum. The reference alignment is preferably present, therefore, if the measuring device finds a temperature maximum or at least a region in which the temperature is higher than in a bordering
10 region. In other words, the optimal alignment of the detection region may be found through a "hotspot search" (where the "hottest spot" refers in practice to a region). The heating of the reference means in the process chamber makes it possible here to ensure that the temperature maximum or the region with
15 a temperature increased relative to its surroundings that is found lies in the process chamber, more particularly in the process volume.

In principle, this approach may also be efficiently used to
20 find multiple reference alignments, corresponding to different longitudinal positions in the process chamber. For this purpose, usefully, a plurality of reference plates of the position reference means are arranged one after another along a longitudinal axis of the process chamber. The arrangement is
25 usefully such that the temperature of each reference plate, in particular at least in a reference region of the respective reference plate, is detectable by means of the measuring device through the opening. A specified temperature distribution can then be generated in the process chamber,
30 including, optionally, a respective temperature distribution for each of the reference plates. In this case, the temperature distributions are usefully specified as a function of the longitudinal position of the corresponding reference plate in the process chamber. Accordingly, each of the

temperature distributions is preferably characteristic of one of the longitudinal positions.

With such a temperature distribution, the temperature usefully
5 changes along the longitudinal axis. Such a temperature distribution may be generated, for example, by corresponding heating of the process chamber – for instance, by supplying power to heating elements selectively.

10 In that case, for each of the reference plates, especially on generation of the temperature distribution assigned to their longitudinal position, it is possible to determine a reference alignment of the detection region of the measuring device that is associated with their longitudinal position in the process
15 chamber. Each reference alignment here is preferably established by the temperature determined in this alignment (with corresponding temperature distribution in the process chamber) fulfilling a specified temperature criterion.

20 Where a respective temperature distribution is generated for each reference plate, it is preferable, for each of the specified temperature distributions, for a respective one of the reference plates to be arranged in the region of a temperature maximum within the process chamber. Expressed
25 alternatively, each of the temperature distributions generated has a temperature maximum at one of the longitudinal positions in the process chamber at which one of the reference plates is also arranged. For this purpose, usefully, for each of the reference plates, the process chamber is heated in such a way
30 that the temperature maximum is formed in the region of the respective reference plate. It is useful, accordingly, for the temperature criterion to be fulfilled by the attainment of a temperature maximum.

Otherwise, if only one temperature distribution is generated, the temperature criterion is usefully fulfilled only for one of the reference plates by attainment of a temperature maximum. The other reference plates may be subject to
5 different temperature criteria – for example, the attainment of a specified fraction of the temperature maximum.

With the aid of the reference alignments identified in this way, it is possible to test the temperature homogeneity in the
10 process chamber. For this purpose, the process chamber is usefully heated with maximum homogeneity and the temperatures which come about for the reference plates are determined in the reference regions. By the assignment of the temperatures thus determined to the position of the reference plates in the
15 process chamber, a temperature distribution along the longitudinal axis is obtained.

In certain circumstances, it is also possible to forgo determination of reference alignments for the purpose of
20 determining such a temperature distribution. For that purpose, it is useful to arrange the multiple reference plates of the position reference means along the longitudinal axis in a specified orientation relative to one another. As a result of the specified orientation, the position of the reference
25 regions in a "temperature picture" taken by means of the measuring device is known. A picture of this kind may be obtained by solid-angle-resolved determination of the temperature in the process chamber by means of the measuring device, after the position reference means has been heated by
30 heating of the process chamber.

In the solid-angle-resolved temperature determination, multiple temperature measurement values at different solid angles are usefully obtained. This may be accomplished, for

example, by aligning the measuring device and/or its detection region to the various solid angles by means of the manipulating device. In this way, in particular, at least part of the possible field of view of the measuring device can be
5 "rasterized". Temperature measurement values obtained by means of the solid-angle-resolved temperature determination therefore form a two-dimensional temperature distribution from the standpoint of the measuring device.

10 Alternatively, of course, it is also possible to perform the solid-angle-resolved temperature determination (i.e. the taking of a "temperature picture") by means of a sensor array of a measuring device embodied accordingly, for instance an (infrared) camera.

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The temperature measurement values from the solid-angle-resolved temperature determination may then be assigned directly to the reference regions of the reference plates, since, indeed, their position in the "picture" is known
20 because of the specified orientation of the reference plates relative to one another. Via the position of the reference plates along the longitudinal axis, it is possible accordingly to derive the temperature distribution along the longitudinal axis.

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In order to also be able to perform a calibration of the measuring device alternatively or additionally to the optimal alignment, a temperature reference means is preferably arranged within the process chamber, more particularly by
30 means of a boat. The temperature reference means is usefully then heated by heating of the process chamber, and a profile of the temperature of the temperature reference means, more particularly of a melt sample of the temperature reference means, is detected here by means of the measuring device. A

melting temperature of the temperature reference means, more particularly of the melt sample, can then be assigned to a temperature from the temperature profile.

- 5 It is possible, for example, to determine a temperature plateau in the temperature profile that is governed by the enthalpy of fusion of the temperature reference means, more particularly of the melt sample, and that marks the attainment of the melting temperature. Accordingly, the melting
10 temperature can be assigned to the temperature plateau.

Alternatively, the measuring device may also be calibrated by means of a conventional temperature sensor, for instance a thermocouple. For that purpose, at least one external
15 temperature measurement means, i.e. a means arranged outside the process chamber, is calibrated by determining a temperature within the process chamber by means of the temperature sensor inserted at least proportionally into the process chamber, and assigning this temperature to measurement
20 data generated on simultaneous measurement of an external temperature of the process chamber by means of the at least one temperature measurement means. Subsequently, the temperature sensor is usefully removed from the process chamber and the measuring device is arranged in front of the
25 process chamber opening. The measuring device can now be calibrated by determining the external temperature of the process chamber by means of the at least one - now calibrated - temperature measurement means, simultaneously with the contactless measurement of the temperature in the process
30 chamber by means of the measuring device. The calibration of the measuring device in this way has the advantage that temperature-sensitive processing methods already established, in existing high-temperature furnaces, can then also be reproduced directly by the measuring device.

It is advantageous here if, prior to the calibration of the measuring device, the detection region of the measuring device is aligned by means of the position reference means. In that
5 case, in particular, the measuring device may also be calibrated by using the measuring device to measure the temperature of one or more reference plates, which are then arranged at different longitudinal positions within the process chamber, and at the same time using the at least one
10 temperature measurement means to determine the external temperature of the process chamber at the corresponding longitudinal positions.

The above-described measurement method in accordance with the
15 second aspect of the invention may be used in particular for calibrating at least one external temperature measurement means of a high-temperature furnace for workpiece processing, more particularly semiconductor processing.

20 A third aspect of the invention therefore relates to a calibration method for at least one temperature measurement means of a high-temperature furnace for workpiece processing, more particularly semiconductor processing, comprising the following steps: i) contactlessly determining a temperature
25 within a process chamber of a high-temperature furnace for the workpiece processing, more particularly semiconductor processing, through a sealable, more particularly sealed, opening of the process chamber, by means of a measuring device arranged in front of the opening; and ii) calibrating at least
30 one temperature measurement means which is arranged outside the process chamber and is configured for determining an external temperature of the process chamber, more particularly the surface temperature of the process chamber in a region on

its external face, on the basis of the contactlessly determined temperature.

For example, in one step, measurement data of the at least one
5 temperature measurement means arranged outside the process chamber may be received. These measurement data usefully characterize an external temperature, measured preferably but not necessarily contactlessly, of the process chamber. In a subsequent step, the contactlessly determined temperature
10 within the process chamber can be assigned to these external measurement data.

Accordingly, the temperature in the process chamber can be derived precisely from the measurement data, i.e. from the
15 external temperature of the process chamber as determined by means of the at least one temperature measurement means. This approach can still be employed reliably even at temperatures of more than 1700°C, since, unlike conventionally employed thermocouples, the measuring device has no relevant
20 temperature restrictions in this temperature range.

The invention is hereinafter elucidated in more detail using figures. Where expedient, elements therein that have the same effect are provided with the same reference symbols. The
25 invention is not restricted to the exemplary embodiments represented in the figures, and not in respect of functional features either. Both the description so far and the description of figures below contain numerous features, some of which are reproduced collectively, as a plurality, in the dependent claims. These features, along with all other
30 features disclosed above and in the description of figures below, however, will also be considered individually, and assembled to form rational further combinations, by the skilled person. In particular, all stated features, in each

case individually and in any desired appropriate combination,
may be combined with the system according to the first aspect
of the invention, with the method according to the second
aspect of the invention and with the calibration method
5 according to the third aspect of the invention.

What is shown by the figures, at least partially
schematically, is the following:

10 Figure 1 shows an example of a system for temperature
determination in a process chamber of a high-
temperature furnace for workpiece processing;

Figure 2 shows an example of a temperature reference means;

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Figure 3A shows an example of a profile determined for the
temperature of a melt sample;

Figure 3B shows an example of an inverted profile of the
20 temperature of a melt sample;

Figure 4 shows an example of a raster comprising temperatures
determined by means of a measuring device;

25 Figure 5 shows an example of a position reference means;

Figure 6 shows an example of a plurality of reference plates
arranged in a process chamber; and

30 Figure 7 shows an example of a method for temperature
determination in a process chamber of a high-
temperature furnace for workpiece processing.

Figure 1 shows an example of a system 1 for temperature determination in a process chamber 2 of a high-temperature furnace 50 – embodied presently as a vertical furnace – for workpiece processing, more particularly semiconductor processing. Provided accordingly is a measuring device 4 which is arranged in front of a sealable opening 3 of the process chamber 2 and which can be moved relative to the process chamber 2 by means of a manipulating device 5, embodied as a positioning device 6, and which is configured for contactless determination of a temperature in the process chamber 2 through the opening 3. The opening 3 is sealed by means of a seal 15 in which there is a window, made of sapphire or quartz for instance. The seal 15 forms a base of the process chamber 2, which is aligned vertically in respect of its longitudinal axis L. The positioning device 6 can be actuated by a controlling device 20. The process chamber 2 is heatable by means of a heating device, for example a plurality of heating elements 7. An external temperature of the process chamber 2, generated by such heating, can be determined by means of (external) temperature measurement means 8.

In the present example, the system 1 comprises a temperature reference means 10 which can be arranged in the process chamber 2, more particularly in a process volume 9 represented using dots, and which can be used to calibrate the measuring device 4 – as described more comprehensively later on below in connection with Figures 2 and 3. The process volume 9 is bounded on the base or seal side by an insulation means 11, here illustratively comprising a so-called "baffle" 12 and a plurality of graphite plates 13 stacked flatly one over another. In order to enable a portal to the process volume 9 via the opening 3, more particularly via the window in the seal 15, the graphite plates 13 are perforated in the middle. The baffle 12, moreover, comprises a baffle channel which

lines up with the perforations of the graphite plates 13 on arrangement in the process chamber 2. The baffle channel and the perforations therefore form a channel 14 in the insulation means 11, through which a temperature in the process volume 9, for example the temperature of the temperature reference means 10, can be determined by means of the measuring device 4. The channel 14 here usefully extends along, more particularly concentrically with, the longitudinal axis L of the process chamber 2. The channel 14 is bounded on the base or seal side by the window and opens at the other end into the process volume 9.

The measuring device 4 may be embodied as a pyrometer or other radiation-measuring instrument, optionally also as an (infrared) camera. It usefully comprises at least one sensor or sensor array which can be used to detect electromagnetic radiation, in the infrared region, for example. This radiation originating from a heated object is characteristic of the temperature of that object.

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To allow the measuring device 4 to reliably detect a temperature of the temperature reference means 10, it is desirable for a detection region 16 of the measuring device 4 to be aligned to the temperature reference means 10. In particular, such an alignment of the detection region 16 may prevent the temperature determined being distorted by an effect of a wall 17 of the channel 14 in the insulation means 11. For example, such an alignment may prevent electromagnetic radiation emitted by the wall 17 of the channel 14 being detected by the measuring device 4.

30

An alignment of the detection region 16 in this way may be performed by means of the positioning device 6. For example, a corresponding (translational) positioning and/or a

corresponding (rotational) alignment of the measuring device 4 may be performed. This is elucidated more comprehensively later on below in connection with Figure 4.

5 Like the measuring device 4, the temperature measurement means 8 are preferably also configured for the contactless – for example radiation-based – determination of the external temperature, more particularly of a surface temperature on the outside of the process chamber 2. As indicated by the dashed
10 lines, the temperature measurement means 8 may for example detect electromagnetic radiation which is emitted by the external face of the process chamber 2 and propagates through between the heating elements 7. Where there is an insulation layer – not represented in Figure 1 – provided around the
15 process chamber 2, that layer usefully has openings to allow the radiation to pass through. In principle, however, different embodiments of the temperature measurement means 8 are also conceivable. For example, the temperature measurement means 8 may alternatively be embodied as thermocouples.

20

Figure 2 shows an example of a temperature reference means 10. The temperature reference means 10 comprises a carrier 18 and a melt sample 19 arranged thereon. The carrier 18 is configured for arrangement in a process chamber of a high-
25 temperature furnace, by means of a so-called "boat", for example. For this purpose, the carrier 18 may have a platelike embodiment, more particularly having a typical wafer form.

The melt sample 19 is usefully made of a material which has a
30 lower melting temperature than the carrier material. As a result, the melt sample 19 can be induced to melt in a targeted way, for example by heating of the process chamber, as shown in Figure 3.

Figure 3A shows an example of a profile 21 of a temperature T of a melt sample which is located in an environment in which the temperature is increased to a temperature above the melting temperature T_s of the melt sample. Over the course of the time t , for example within a few 100 ms after increasing the ambient temperature to a level above the melting temperature T_s , the temperature T of the melt sample rises to the melting temperature T_s . The temperature T of the melt sample persists there until the melt sample is molten.

Expressed alternatively, the profile 21, specifically because of the enthalpy of fusion of the melt sample, forms a temperature plateau 22 at the melting temperature T_s . Only after melting does the temperature T of the (now liquid) melt sample rise further.

Figure 3B shows the inverted profile, specifically showing an example of a profile 21 of a temperature T of a melt sample which is located in an environment in which the temperature is lowered from a temperature above the melting temperature T_s of the melt sample to a temperature below the melting temperature T_s . In this case, the temperature plateau 22 forms until the melt sample is fully solidified.

The measuring device 4 shown in Figure 1 can therefore be calibrated by the determination of such a temperature profile 21 immediately after the internal temperature of the process chamber 2 has been increased to a temperature above a melting temperature T_s of the temperature reference means 10 or has been lowered to a temperature below the melting temperature T_s . For this purpose, the controlling device 20 is preferably configured to identify a temperature plateau 22 in the measurement data of the measuring device 4 that are generated when the temperature profile 21 is recorded. The controlling device 20 can then assign the previously known melting

temperature T_s of the temperature reference means 10, more particularly of the melt sample, to the measurement data corresponding to the relevant plateau temperature.

5 The measuring device 4 calibrated in this way can be used for particularly precise calibration of the temperature measurement means 8 shown in Figure 1. For this purpose, the controlling device 20 is preferably configured to detect a temperature in the heated process chamber 2 using the -
10 usefully calibrated - measuring device 4 and assign it to measurement data of the temperature measurement means 8 that actually characterize an external temperature of the process chamber 2. In the general operation of the high-temperature furnace 50, the internal temperature of the process chamber 2
15 may then be reliably derived from the measurement data of the temperature measurement means 8.

Figure 4 shows an example of a raster 23 composed of temperatures T (indicated as shading or a white area)
20 determined contactlessly by means of a measuring device through an opening of a process chamber. The raster 23 comes about through movement of the measuring device in two degrees of freedom x , y (for example, translated and/or swivelled). The movement of the measuring device also causes a change in
25 the position of a detection region 16 (indicated as a circle) of the measuring device, to which a determined temperature T is assigned. The raster 23 therefore shows the spatial temperature profile from the standpoint of the measuring device.

30

In the example shown, the temperatures T indicated with shading are lower than the temperatures T indicated as a white area. In the event of a change in the alignment of the detection region 16 of the detecting device of the measuring

device 4 from Figure 1, these lower temperatures T may be assigned, for example, to the temperature of the wall 17 of the channel 14 in the insulation means 11. The higher temperatures T in the centre of the raster 23 represented may
5 be assigned conversely to the temperature reference means 10 arranged in the process volume 9.

As a result of change in the arrangement of the measuring device 4 relative to the process chamber 2 in respect of at
10 least two degrees of freedom (x , y), for example two degrees of translational freedom (movement in a plane parallel to the opening 3) and two degrees of rotational freedom (tilting relative to the longitudinal axis L), it is possible accordingly to identify an alignment of the detection region
15 16 in which the temperature T in the process chamber 2 or of a measurement target arranged therein, for instance of the temperature reference means 10, can be determined reliably and without influences by the wall 17 of the channel 14.

20 Alternatively or additionally to the temperature reference means 10 shown in Figure 1, this "optimal" alignment of the detection region 16 may in principle also be found by means of a different measurement target, for instance a dedicated position reference means.

25 It is likewise conceivable, moreover, that instead of the "rasterizing" of the volume in the process chamber 2 that is accessible through the opening 3, through movement of the measuring device 4, a "picture" is taken by means of a sensor
30 array of a correspondingly embodied measuring device 4, for instance an (infrared) camera.

Figure 5 shows a position reference means 24 embodied as a perforated plate 25. The position reference means 24 comprises

a projection 26 which defines a reference region 27, drawn using dashes. The projection 26 protrudes into the perforation 28, more particularly toward the middle thereof. Consequently, the reference region 27 is arranged in a region at the edge 29
5 of the perforation 28.

Accordingly, on arrangement of the position reference means 24 in the process chamber 2 from Figure 1, in particular instead of the temperature reference means 10 shown in that figure, an
10 alignment of the detection region 16 of the measuring device 4 to the reference region 27 can be found using the approach described in connection with Figure 4.

Furthermore, the embodiment of the position reference means 24
15 as a perforated plate 25, as shown, additionally allows the temperature of an object arranged in the process chamber 2 behind the position reference means 24 to be determined also by corresponding alignment of the detection region 16. This can be utilized to investigate the temperature homogeneity in
20 the process chamber 2, as elucidated in more detail in connection with Figure 6.

Figure 6 shows an example of a plurality of – three, purely illustratively – reference plates 30 of a position reference
25 means 24. The reference plates 30 are arranged, by means for example of a boat 31 only parts of which are shown, in a process chamber 2 of a high-temperature furnace at various longitudinal positions P1, P2 and P3 in relation to a longitudinal axis L of the process chamber 2.

30

Each of the reference plates 30 is embodied as a perforated plate which has a projection 26 pointing toward the middle of the perforation. Apart from the inwardly protruding projection 26, the perforations 28 of the perforated plates have a

substantially circular form. In the arrangement within the process chamber 2, the perforations 28 line up along the longitudinal axis L.

5 The reference plates 30 are arranged one after another along the longitudinal axis L, being more particularly oriented relative to one another, in such a way that the temperature of each reference plate 30 can be determined by means of a measuring device through an opening in the process chamber
10 base (compare Figure 1). In particular, the reference plates 30 are arranged, being more particularly oriented relative to one another, in such a way that electromagnetic radiation emitted from the projections 26 can propagate substantially along the longitudinal axis L through the opening to the
15 measuring device. The reference plates 30 are therefore usefully arranged, being more particularly oriented relative to one another, in such a way that, as viewed along the longitudinal axis L, none of the projections 26 is concealed by another projection 26 or itself conceals a projection 26
20 behind it.

For example, as can already be seen in Figure 5, the projections 26 may have the form of a circle sector. All the projections 26 together usefully cover 360° . In principle,
25 however, other forms of the projections 26 are also conceivable, circle segments for example.

As a result of the fact that, on corresponding alignment of a detection region of the measuring device to the respective
30 projection 26 or to the reference region thereby defined (compare Figure 5), the temperature of one of the reference plates 30 arranged at the various longitudinal positions P1, P2 and P3 can be determined in a targeted manner, it is also

possible to determine a temperature distribution in the process chamber 2 along the longitudinal axis L.

In order to be able to determine the temperatures in a
5 targeted manner at the longitudinal positions P1, P2 and P3,
it is expedient to determine, in advance, reference alignments
for the detection region that correspond to the position of
the projections 26. By "moving to" such a reference alignment,
i.e. by aligning the detection region into such a reference
10 alignment, the temperature of the associated reference plate
30 can then be determined.

The reference alignments may be determined by generating
different temperature distributions in the process chamber 2,
15 by means for example of targeted actuation of the heating
elements 7 shown in Figure 1 by the controlling device 20. In
each temperature distribution thus generated, there is
usefully a temperature maximum here in the region of one of
the reference plates 30. In the case of the three reference
20 plates 30 shown in Figure 6, for example, it is possible to
generate a temperature distribution having a maximum at the
longitudinal position P1, for instance in a lower end of the
process chamber 2 or at least of the process volume 9 shown in
Figure 1; a temperature distribution having a maximum at the
25 position P2, for instance in the middle of the process chamber
2 or at least in the middle of the process volume 9; and a
temperature distribution having a maximum at the longitudinal
position P3, for instance at an upper end of the process
chamber 2. As a result, one of the projections 26 is heated,
30 usefully, to a greater extent than the rest of the projections
26.

For each of these temperature distributions generated, it is
then possible, using the approach already elucidated earlier

on above in connection with Figure 4, to determine the position of the most greatly heated projection 26.

Correspondingly, the alignment of the detection region for which the temperature determined fulfils a predetermined
5 temperature criterion – for example, attains a temperature maximum – can be identified as a reference alignment for the corresponding projection 26.

Where the alignment of the reference plates 30, more
10 particularly of the projections 26, in the process chamber 2 is specified or already known, it may also be possible to determine a temperature distribution along the longitudinal axis L without explicitly identifying the reference
alignments, and so to shorten the method. For this purpose,
15 the temperature in the process chamber is usefully determined with solid-angle resolution, for example in raster manner as in connection with Figure 4. In the resulting picture, i.e. the two-dimensional temperature distribution (cf. raster from
Figure 4), the temperatures determined may then be assigned to
20 the specified or known projections 26 on the basis of the position of said temperatures in the picture.

In certain circumstances, through the use of a position
reference means 24 with multiple reference plates 30, a
25 particularly precise calibration of the temperature measurement means 8 shown in Figure 1 can also be achieved. For that purpose, the reference plates 30 are usefully arranged at the same height, with a respective temperature
measurement means 8, within the process chamber 2. By
30 generating corresponding temperature distributions with a temperature maximum at the longitudinal position P1, P2, P3 of a respective one of the reference plates 30, it is then possible to assign a maximum temperature determined by means
of the measuring device 4 – and corresponding to the

temperature of the reference plate 30 which is the closest to the temperature maximum - to measurement values of the temperature measurement means 8 corresponding thereto - that is, situated at the same height. Accordingly, each temperature measurement means 8 can be calibrated separately, allowing temperature inhomogeneities in the process chamber 2, in particular, to be taken into account.

In this case as well, however, it is conceivable to shorten the method and to utilize a specified or known alignment of the reference plates 30 in order to be able to carry out the calibration of the temperature measurement means 8 in only one "measurement pass", i.e. with only a single temperature distribution in the process chamber 2. Here, the temperature measurement values obtained on solid-angle-resolved determination of the temperature in the process chamber 2 are usefully assigned to the corresponding reference plate 30 and its corresponding temperature measurement means 8 on the basis of the position of said measurement values in the two-dimensional raster (cf. Figure 4).

An optional possibility, aside from the three reference plates 30 shown in Figure 6, is to arrange further perforated sheets without projection 26 in the process chamber 2 in order to increase the thermal load. The temperature of these further perforated sheets is usefully not detected by the measuring device.

Figure 7 shows an example of a method 100 for temperature determination in a process chamber of a high-temperature furnace for workpiece processing, more particularly semiconductor processing.

In a method step S1, a temperature reference means is arranged via an opening in a process chamber, with the aid of a boat, for example. The process chamber is then usefully sealed with a process chamber seal, in which there is a window made.

5

In a further method step S2, a measuring device for contactlessly determining a temperature in front of the (sealed) opening, more particularly in front of the window, is arranged outside the process chamber. Here, the measuring
10 device is usefully arranged in such a way that a temperature within the process chamber, more particularly of the temperature reference means, can be determined contactlessly by means of the measuring device. Additionally, in method step S2, the process chamber can be heated. The temperature in the
15 process chamber here is preferably increased to a temperature which is lower than a melting temperature of a melt sample of the temperature reference means.

In a further method step S3, the temperature within the
20 process chamber, more particularly of the temperature reference means, is determined by means of the measuring device through the opening of the process chamber.

A further method step S4 preferably involves testing whether a
25 cessation criterion is met. If not, the alignment of a detection region of the measuring device is altered by means of a manipulating device in method step S5. For example, the arrangement of the measuring device relative to the process chamber can be changed by means of a positioning device, for
30 instance by moving the measuring device translationally in a plane parallel to the opening and/or tilting it relative to a longitudinal axis of the process chamber. Subsequently, method step S3 is executed again – that is, a temperature is determined again.

If, conversely, the cessation criterion is met, the method continues with step S6. The cessation criterion may be met, for example, if an alignment of the detection region or an arrangement of the measuring device relative to the process chamber in which a specified temperature criterion is met has been or can be determined on the basis of a multiplicity of temperatures determined. The temperature criterion is usefully met if a temperature maximum is determined or at least one region is identified in which the temperature is higher than in a bordering region.

The alignment of the detection region or the corresponding arrangement of the measuring device relative to the process chamber may be stored as a reference alignment.

In method step S6, the temperature in the process chamber is preferably increased to a temperature above a melting point of the melt sample. At the same time or at least immediately thereafter, the measuring device determines a profile of the melt sample temperature. In a further method step S7, a plateau temperature can then be determined from the temperature distribution, and the melting temperature of the melt sample is assigned to this temperature.

The measuring device thus calibrated can be used to carry out a calibration method 200 for at least one temperature measurement means arranged outside the process chamber, for measuring an external temperature of the process chamber. To do this, usefully, first the melt sample is removed from the process chamber and replaced by another measurement target, for example a position reference means. Subsequently, the process chamber can be heated again and a temperature in the process chamber determined by means of the calibrated

measuring device. At the same time, preferably, an external temperature, for example a surface temperature, of the process chamber is detected by means of the external temperature measurement means. For the calibration, the temperature
5 determined by means of the calibrated measuring device is assigned to the synchronously obtained measurement data of the temperature measurement means.

The method steps S3 to S5 may optionally be carried out again
10 for the calibration of multiple external temperature measurement means arranged at different positions along the process chamber, after the temperature reference means has been replaced by the position reference means. It is optionally possible as a result to determine multiple
15 reference alignments for the detection region or the measuring device, corresponding to the different longitudinal positions. As a result, it is possible not only to test the temperature homogeneity in the process chamber but also, optionally, to calibrate the plurality of temperature measurement means
20 individually.

List of reference symbols

	1	System
	2	Process chamber
5	3	Opening
	4	Measuring device
	5	Manipulating device
	6	Positioning device
	7	Heating element
10	8	Temperature measurement means
	9	Process volume
	10	Temperature reference means
	11	Insulation means
	12	Baffle
15	13	Graphite plate
	14	Channel
	15	Seal
	16	Detection region
	17	Wall
20	18	Carrier
	19	Melt sample
	20	Controlling device
	21	Temperature profile
	22	Temperature plateau
25	23	Raster
	24	Position reference means
	25	Perforated plate
	26	Projection
	27	Reference region
30	28	Perforation
	29	Edge
	30	Reference plate
	31	Boat

50	High-temperature furnace
100	Method
5	200 Calibration method
	S1 Arrangement of temperature reference means in process chamber
	S2 Arrangement of measuring device in front of opening
10	S3 Detection of temperature in process chamber
	S4 Test of whether cessation criterion met
	S5 Changing alignment of detection region
	S6 Increasing temperature and determining melt sample temperature profile
15	S7 Determining plateau temperature
	L Longitudinal axis
	P1 Longitudinal position
	P2 Longitudinal position
20	P3 Longitudinal position
	T Temperature
	x, y Degree of freedom
	t Time
	T _s Melting temperature

Claims

1. System (1) for temperature determination in a process
chamber (2) of a high-temperature furnace (50) for
5 workpiece processing, more particularly semiconductor
processing, having a heatable process chamber (2) which
comprises an opening (3),
characterized by
a measuring device (4) arranged in front of the opening,
10 for contactlessly determining a temperature (T) within
the process chamber (2) through the opening (3).
2. System (1) according to Claim 1,
characterized by
a manipulating device (5) for aligning a detection region
15 (16) of the measuring device (4).
3. System (1) according to Claim 2,
characterized
in that the manipulating device (5) comprises a
positioning device (6) for moving the measuring device
20 (4) relative to the process chamber (2).
4. System (1) according to Claim 3,
characterized
in that the positioning device (6) for moving the
measuring device (4) is configured in at least two
25 degrees of freedom (x, y).
5. System (1) according to any of the preceding claims,
characterized by

- at least one temperature measurement means (8) arranged outside the process chamber (2) for determining an external temperature of the process chamber (2), and
 - a controlling device (20) configured to calibrate the at least one temperature measurement means (8) on the basis of a temperature (T) within the process chamber (2) that is determined by means of the measuring device (4).
- 6. System (1) according to any of the preceding claims, characterized by at least one temperature reference means (10) which can be arranged within the process chamber (2), for calibrating the measuring device (4).
- 7. System (1) according to Claim 6, characterized in that the temperature reference means (10) comprises a melt sample (19) which is held by a carrier (18) and has a predefined melting temperature (T_s).
- 8. System (1) according to Claim 7, characterized in that the melt sample (19) comprises silicon or ruthenium carbide and/or the carrier (18) is made of graphite, rhenium carbide, platinum carbide, iridium carbide or rhodium carbide.
- 9. System (1) according to any of the preceding claims, characterized by a position reference means (24) which can be arranged in the process chamber (2), for aligning the detection

region (16) of the measuring device (4) within the process chamber (2).

10. System (1) according to Claim 9,
characterized

5 in that the position reference means (24) comprises at least one perforated plate (25) which is embodied in such a way that on arrangement in the process chamber (2), a temperature (T) of the perforated plate (25) is determinable in a reference region (27) at the edge (29)
10 of the perforation (28) by means of the measuring device (4) through the opening (3).

11. System (1) according to either of Claims 9 and 10,
characterized

15 in that the position reference means (24) comprises a plurality of position reference plates (30) which can be arranged one after another along a longitudinal axis (L) of the process chamber (2) and which are embodied in such a way that at least in a predetermined sequence and/or alignment of the reference plates (30) arranged in the
20 process chamber (2) relative to one another, the temperature (T) is determinable in a reference region (27) of each reference plate (30) by means of the measuring device (4) through the opening (3).

12. System (1) according to any of Claims 9 to 11,
25 characterized

in that the position reference means (24) has a projection (26) which defines a reference region (27) in which, on arrangement of the position reference means (24) in the process chamber (2), a temperature (T) of the
30 position reference means (24) is detectable by means of the measuring device (4) through the opening (3).

13. Method (100) for temperature determination in a process chamber (2) of a high-temperature furnace (50) for workpiece processing, more particularly semiconductor processing, comprising:

- 5 – arranging (S2) a measuring device (4) for contactlessly determining a temperature (T) in front of an opening (3) of a heatable process chamber (2) of a high-temperature furnace (50) for workpiece processing, more particularly semiconductor processing; and
- 10 – measuring (S3) a temperature (T) within the process chamber (2) through the opening (3) by means of the measuring device (4).

14. Method (100) according to Claim 13, characterized

- 15 in that a detection region (16) of the measuring device (4), before the determination of the temperature (T), is aligned (S5) by means of a manipulating device (5) to a field of view which is defined by the opening (3) and/or an insulation means (11) arranged within the process
- 20 chamber (2) for thermally insulating the region at the opening (3).

15. Method (100) according to either of Claims 13 and 14, characterized

- 25 in that the measuring device (4) is aligned relative to the process chamber (2) with respect to at least two degrees of freedom (x, y) by means of a positioning device (6).

16. Method (100) according to any of Claims 13 to 15, characterized

- 30 in that

- a position reference means (24) having a reference region (27) is arranged in the process chamber (2),
 - the position reference means (24) is heated by heating of the process chamber (2), and
 - 5 – an alignment of the detection region (16) of the measuring device (4) is identified as a reference alignment in which the measuring device (4) detects a temperature (T) in the reference region (27) if the temperature (T) determined in this alignment fulfils a
 - 10 specified temperature criterion.
17. Method according to any of Claims 13 to 16, characterized in that
- 15 – a plurality of reference plates (30) of a position reference means (24) are arranged one after another along a longitudinal axis (L) of the process chamber (2);
 - a specified temperature distribution is generated in the process chamber (2), and
 - 20 – for each of the reference plates (30), a reference alignment of the detection region (16) of the measuring device (4), said alignment being associated with their longitudinal position (P1, P2, P3) in the process chamber (2), is determined at which a temperature (T)
 - 25 determined by means of the measuring device (4) fulfils a specified temperature criterion.
18. Method according to any of Claims 13 to 17, characterized in that
- 30 – a plurality of reference plates (30) of a position reference means (24) each having a reference region

(27) are arranged one after another along a longitudinal axis (L) of the process chamber (2) in a specified orientation relative to one another,

- 5 – the position reference means (24) is heated by heating of the process chamber (2),
- the temperature in the process chamber (2) is determined with solid-angle resolution by means of the measuring device (4), so that a plurality of temperature measurement values are determined at
- 10 different solid angles,
- a temperature distribution along the longitudinal axis (L) of the process chamber (2) is determined on the basis of assignment of the temperature measurement values to the reference regions (27) of the reference
- 15 plates (30).

19. Method (100) according to any of Claims 13 to 18, characterized in that

- 20 – a temperature reference means (10) for calibrating the measuring device (4) is arranged (S1) within the process chamber (2),
- the temperature reference means (10) is heated by heating of the process chamber (2) and a profile (21) of the temperature (T) of the temperature reference
- 25 means (10) is detected (S6) here by means of the measuring device (4), and
- a melting temperature (T_s) of the temperature reference means (10) is assigned (S7) to a temperature (T) from the temperature profile (21).

20. Method (100) according to any of Claims 13 to 18,
characterized
in that

- at least one temperature measurement means (8) arranged
outside the process chamber (2) is calibrated by
determining a temperature within the process chamber
(2) by means of a temperature sensor inserted at least
proportionally into the process chamber (2) and
assigning it to measurement data which are generated on
simultaneous measurement of an external temperature of
the process chamber (2) by means of the at least one
temperature measurement means (8), and
- the measuring device (4) is calibrated by measuring the
external temperature of the process chamber (2) by
means of the at least one calibrated temperature
measurement means (8) and assigning it to measurement
data which are generated on simultaneous contactless
measurement of the temperature in the process chamber
(2) by means of the measuring device (4).

21. Calibration method (200) for at least one temperature
measurement means (8) of a high-temperature furnace (50)
for workpiece processing, more particularly semiconductor
processing, comprising:

- contactlessly determining a temperature (T) within a
process chamber (2) of a high-temperature furnace (50)
for the workpiece processing through an opening (3) of
the process chamber (2), by means of a measuring device
(4) arranged in front of the opening (3); and
- calibrating at least one temperature measurement means
(8) which is arranged outside the process chamber (2)
and is configured for determining an external

temperature of the process chamber (2), on the basis of the contactlessly determined temperature (T).