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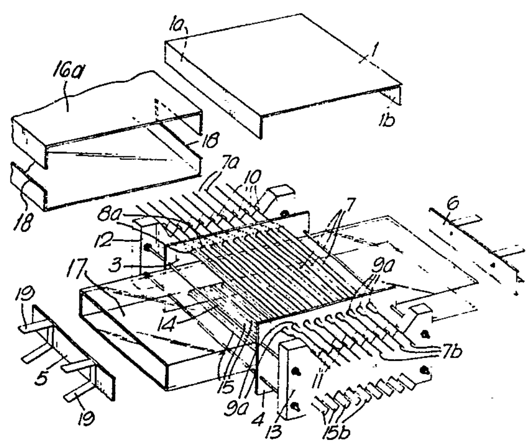
None

(58) Field of search
F4B

(54) **A Furnace for Rapidly Heating Semiconductor Bodies**

(57) The furnace comprises a chamber formed from reflecting side walls (1—6) and a plurality of heat radiation lamps (7, 15) within the chamber. The semi-conductor to be treated is inserted within a quartz sleeve (17) which is accommodated between the lamps (7, 15). The ends of the quartz sleeve are closed by reflecting side walls (5, 6) which define part of the above chamber. The configuration of lamps and their images formed by reflection in the walls forming the chamber approximates to an array of infinite size.

Fig.1.



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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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Fig.1.

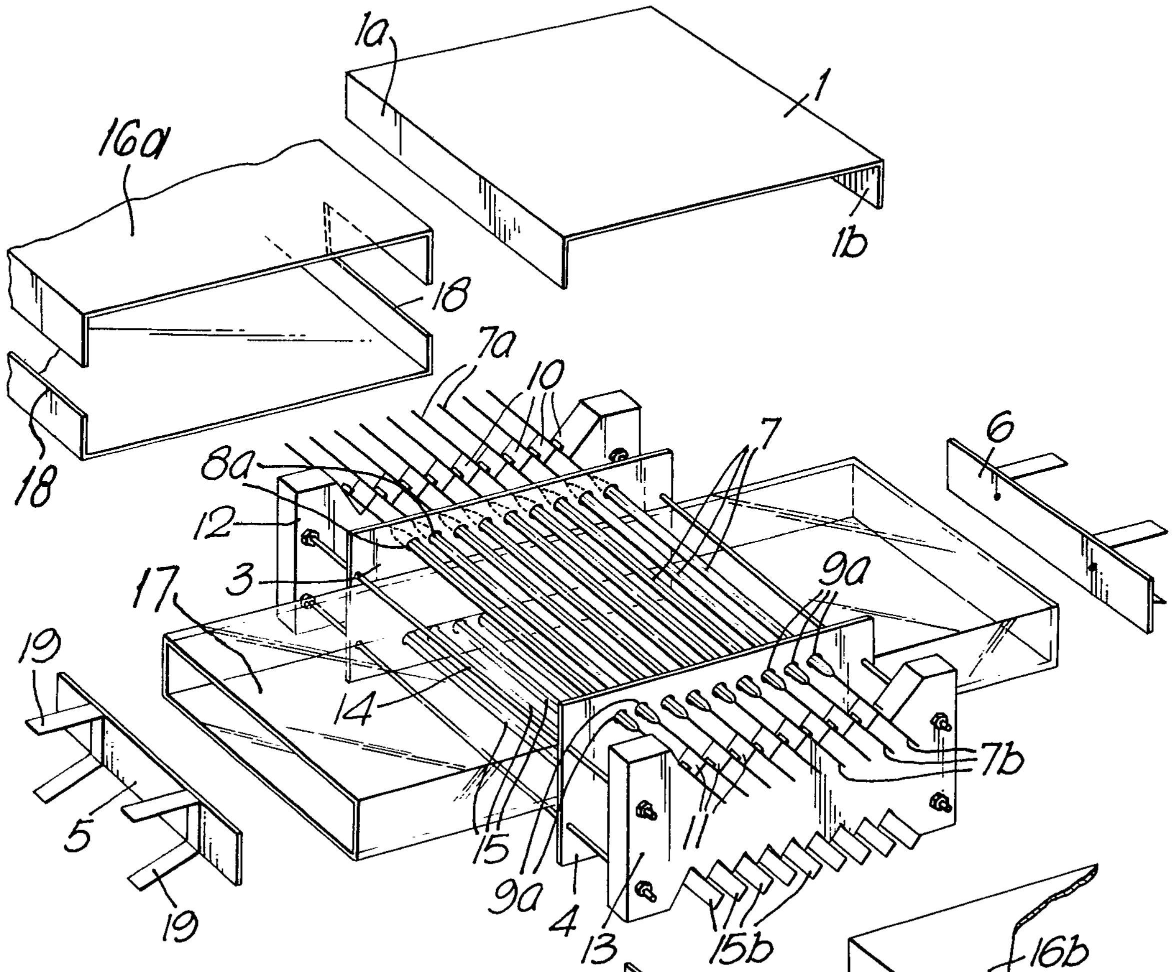


Fig.2.

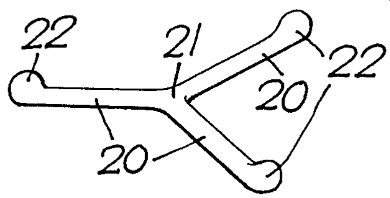


Fig. 3.

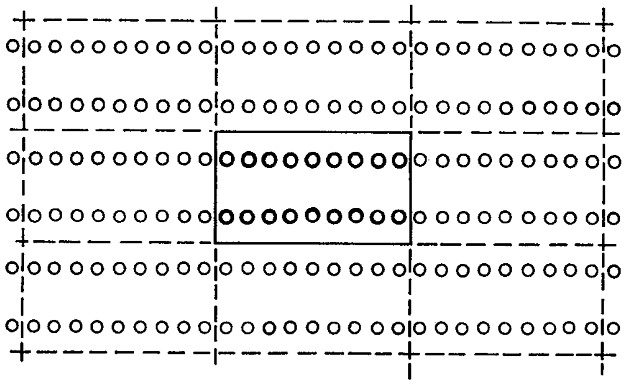


Fig. 4.

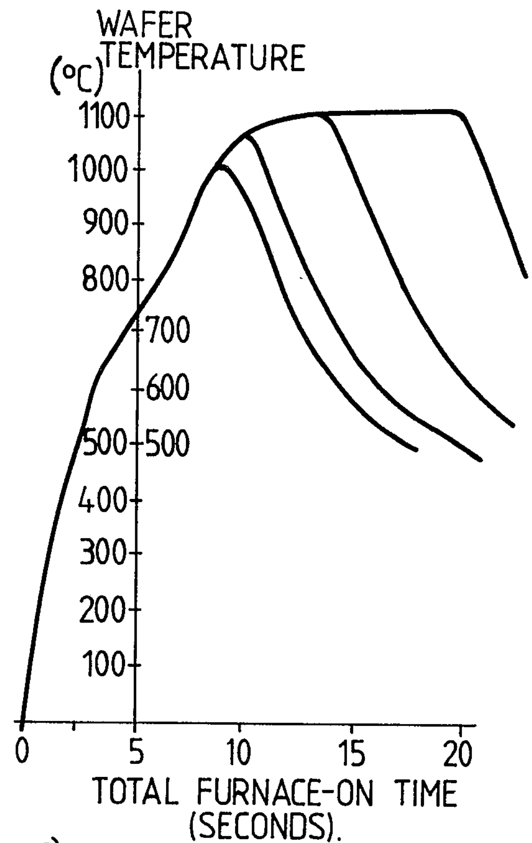
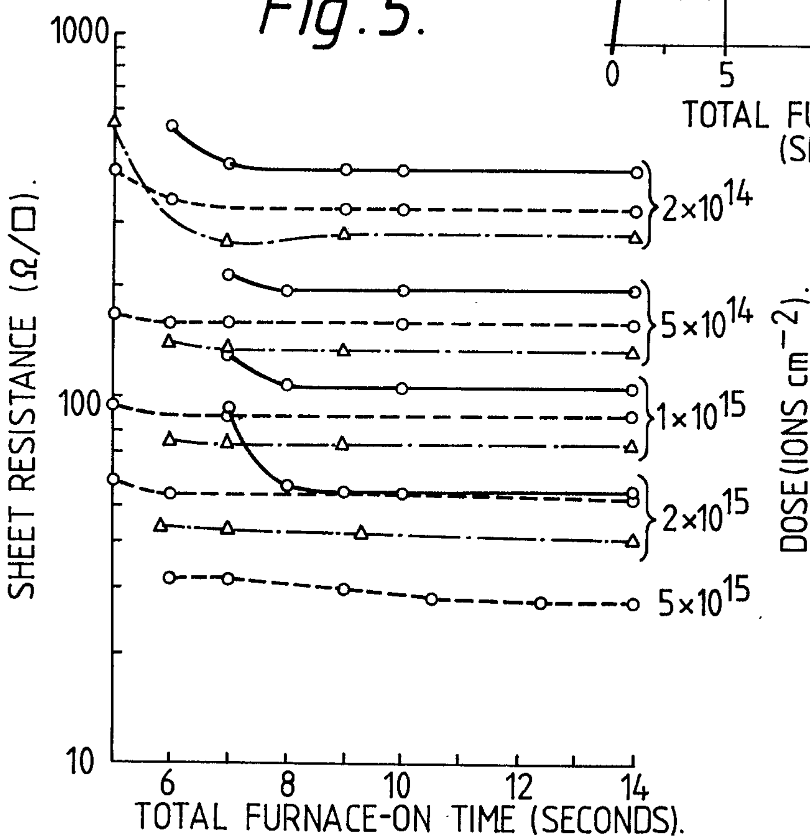


Fig. 5.



SPECIFICATION

A Furnace Suitable for Heat-Treating Semiconductor Bodies

This invention relates to a furnace particularly, but not exclusively, for heat-treating a semiconductor body in the form of a so-called 'wafer'.

In the semiconductor industry discrete electronic components and integrated circuits are formed in a thin slice or wafer of semiconductor material. At various stages during device fabrication the wafer has to be subjected to a heat-treatment. For example, in the process of locally modifying the conductivity or conductivity type of the semiconductor wafer by the well-known technique of ion-implantation the semiconductor crystal structure is damaged and the wafer then has to be subjected to a heat treatment in order to restore the crystal structure and also to activate the implanted impurities. This heat treatment is often referred to as annealing. Traditionally, the annealing process is carried out by heating the semiconductor wafer in a conventional electric oven. In order to achieve uniform annealing over the whole wafer surface and to avoid causing undue stress which in turn causes defects and distortions in the wafer undergoing the heat treatment it is important to heat the wafer uniformly. To this end it is usual practice to introduce the wafer into the oven at a relatively low temperature, say 600°C, and slowly to ramp the temperature up to the level required for annealing. However, because a conventional oven comprises components of high thermal capacity, it is not possible to change the temperature rapidly. Raising the temperature of the wafer uniformly to a sufficiently high temperature, that is to say, to about 1000°C typically takes in the order of 30 minutes. Not only are such long heat treatments uneconomic, but they can also cause undesired diffusion and redistribution of the implanted impurity which impairs the accuracy of device fabrication, thus preventing the use of very small device dimensions and restricting the designer's freedom to specify impurity location and concentration.

In recent years much research effort has been directed to establishing new techniques for rapidly annealing ion-implanted semiconductor wafers. In particular high powered laser and electron beams have been used successfully to heat the wafer many times more quickly than is possible with a conventional oven. However, these techniques are still largely experimental, involving cumbersome and expensive equipment which is not readily transferable from the laboratory into the production environment.

British Patent Application GB 2,065,973A discloses a more simple and less expensive furnance apparatus which comprises a chamber for receiving the semiconductor wafer to be heated and a plurality of incoherent light sources in the form of tungsten-halogen lamps. Each lamp is sited in the area of the focus of a parabolic mirror which concentrates the radiation from the lamps onto the wafer. Unfortunately, however, it has been found that this arrangement does not heat the wafer uniformly. On the contrary, the heating effect can vary substantially—even by as much as 30%—at different locations across the wafer. Such temperature variations can have an uncontrollable effect on the electrical characteristics of the semiconductor devices being manufactured both directly, by causing non-uniform electrical activation and indirectly by causing stress in the wafer resulting in undesired defects and distortions.

According to the present invention a furnace comprising a chamber for receiving a body to be heated, and a plurality of heat radiation lamps for heating said body is characterized in that the chamber has reflecting walls, and in that the lamps are so arranged inside the chamber with respect to the walls that the configuration of lamps and their images formed by reflection in said walls approximates to an array of infinite size.

A furnace according to the invention is relatively straightforward and inexpensive to construct. Moreover, it can provide not only rapid but also surprisingly uniform heating of the body to be heated, and as such is ideally suited for heat-treating production-size semiconductor wafers in the factory environment.

The high degree of heating uniformity can be maximized if the area occupied by the lamps is at least as extensive as the body to be heated and if the spacing between adjacent lamps is less than the spacing between the lamps and the location in the chamber of the body to be heated.

For simplicity of design and construction it is preferable that the chamber of the furnace is substantially rectangular and has plane reflecting walls, that is to say that the walls and the various sections of the chamber are all substantially rectangular.

The furnace may comprise a single set of heat lamps each at substantially the same distance from one wall of the chamber. A second set of lamps may also be included in which second set each lamps is at substantially the same distance from a second opposite wall of the chamber. For optimum uniformity of heating in either case it is preferable for the lamps in each set to be substantially equally spaced from each other.

Although the configuration of lamps and their images may be a regular array in some circumstances an irregular array may be desirable instead, for example to compensate for any localized hot-spots on the wafer. Thus when the furnace comprises two sets of lamps as described above the lamps of one set, when viewed in a direction orthogonal thereto, may be present at locations intermediate the lamps of the other set.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is an exploded, isometric view of a furnace in accordance with the invention for heat-treating a semiconductor wafer,

Figure 2 is an isometric view of a carrier for introducing a semiconductor wafer into the furnace of Figure 1,

Figure 3 is a schematic sectional view of part of the furnace of Figure 1 showing the array of lamps and some of their reflected images,

Figure 4 is a graph showing temperature versus time for a semiconductor wafer heated in a furnace in accordance with the invention, and

Figure 5 is a graph showing sheet resistance versus time for various ion-implanted semiconductor wafers heated in a furnace in accordance with the invention.

The furnace shown as an exploded isometric view in Figure 1 is suitable for heat-treating semiconductor wafers and comprises a rectangular chamber for receiving the semiconductor wafer to be heated. The chamber is defined by six component parts as follows, a 145x150 mm. rectangular top wall 1 and a similar rectangular bottom wall 2 each comprising integral 29x145 mm. side wall portions 1a, 1b and 2a, 2b respectively at two opposite edges; two 95x150 mm. rectangular side walls 3, 4 orthogonal to the side wall portions 1a, 1b; and two 30x130 mm. separate side wall portions 5, 6 which are parallel to the side wall portions 1a, 2a and 1b, 2b respectively and which are described in more detail below. The walls of the chamber are all plane and the chamber itself is rectangular in section. With the wall dimensions given above the overall dimensions of the chamber are 145x150x95 mm. The walls are made of polished stainless steel and their inwardly-directed faces are gold-plated so that they reflect infra-red radiation.

A first set of nine heat radiation lamps 7 are present in the chamber extending between the side walls 3 and 4. The lamps 7 are mutually parallel straight filament lamps which emit incoherent radiation. They are arranged in a plane array each at the same distance of approximately 15 mm. from the lamp centre to the top wall 1. The lamps 7 are equally spaced and the distance between the centres of adjacent lamps is approximately 14 mm. While the number of lamps is not critical to the operation of the furnace it is preferable for optimum heating uniformity that the area occupied by the set of lamps 7 is at least as extensive as the body to be heated. In the present embodiment the lamps are sufficiently long to extend through circular apertures 8a and 9a in the side walls 3 and 4 respectively. Extended spade-like terminals 7a, 7b at opposite ends of each lamp 7 are located in V-shaped grooves 10 and 11 of supporting members 12 and 13 respectively and are secured against the groove walls for example with screws to provide support for the lamps 7. Electrical connections (not shown in the Figure) can be made to the terminals of each lamp in the usual way.

The supporting members 12 and 13 are made of an insulating material such as Sindanyo (RTM) which is an asbestos-based composite material. They are maintained in fixed spaced relation to one another by four screw-threaded bolts 14 which extend the full width of the chamber through the side walls 3, 4 and through the supporting members 12, 13 themselves. Each bolt 14 is secured at both ends with two nuts in conventional manner.

The furnace also comprises a second set of nine similar heat lamps 15 extending through apertures in the side walls 3, 4 and supported in V-shaped grooves in the insulating members 12, 13 in exactly the same manner as the first set of lamps. This second lamp set is arranged in a plane array parallel to but spaced apart from the first set and each lamp of the second set is at the same distance of approximately 15 mm., from the lamp centre to the bottom wall 2. Thus the first and second sets of lamps are mutually parallel and spaced apart by approximately 65 mm. The space between the two lamp sets, and more particularly the plane midway therebetween, is where the semiconductor wafer will be located for the heat treatment.

Suitable lamps for use in this furnace are 0.5 kW tungsten filament heat lamps currently available from Philips under Catalogue No. 13169X. These lamps comprise a quartz envelope approximately 170 mm. long containing the filament and have extended spade-like terminals with several fixing holes at each end. The radiation emitted by these lamps has a peak wavelength of approximately 1.2 micrometres.

The apertures 8a, 9a in the walls 3, 4 are approximately 15 mm. in diameter whereas the diameter of the lamps 7, 15 is only 10 mm. Thus the lamps 7, 15 can be supported such that they do not contact the walls 3, 4, the apertures 8a, 9a providing clearance around the full circumference of the lamps. Thus a cooling atmosphere such as air can be introduced into the chamber via the apertures 8a, 9a to cool the lamps. For this purpose rectangular ducts 16a and 16b made for example of aluminium are provided around the walls of the chamber in abutting relation with each other. Slots 18 are present in the side walls of the ducts 16a, 16b so that they can be fitted around the sleeve 17 (described below). The cooling atmosphere is thus directed along the duct 16a, enters the chamber through the apertures 8a, and leaves via apertures 9a along the duct 16b.

The furnace also comprises an open-ended quartz sleeve 17 which is rectangular in cross-section and which is accommodated between the two sets of lamps 7, 15. The open ends of the sleeve 17 are orthogonal to the apertured side walls 3, 4 of the chamber and to the two sets of lamps 7, 15. The sleeve 17 which is made of quartz and so is transparent to the infra-red radiation from the lamps shields the wafer to be heated from the cooling atmosphere which could cause contamination and temperature non-uniformities.

In order to minimize thermal mass so that rapid temperature changes are facilitated the semiconductor wafer which is to be subjected to the heat treatment can be inserted into the sleeve 7 supported on, for example a quartz tripod carrier of the form shown in Figure 2. This carrier comprises three co-planar symmetrically arranged radially extending arms 20 joined at the centre 21 and having raised end portions 22 which engage the semiconductor wafer to be heated and support it in a plane mid-way between the two sets of lamps 7, 15 when the carrier is inserted into the quartz sleeve 17 of the furnace.

The wall portions 5 and 6 of the chamber fit slideably within the sleeve 17 which thus act as removable end stops. When the furnace is in use these end stops 5, 6 are positioned so that they are approximately co-planar with the wall portions 1a, 2a and 1b, 2b respectively. To facilitate insertion and removal of the end stops they are provided each with two outwardly directed grips 19 formed from substantially U-shaped strips of stainless steel fastened to the wall portion, for example with screws.

When the furnace is in use the semiconductor wafer to be heated is positioned in the quartz sleeve and the heat lamps 7, 15 of both sets are switched on. The inwardly directed faces of the chamber walls are all gold-plated as mentioned earlier and thus they reflect the heat radiation emitted by the lamps.

Figure 3 shows the effect obtained when the lamps are switched on and is a schematic sectional view through the chamber of the furnace. The rectangle drawn with a continuous line at the centre of the Figure represents the reflecting walls of the chamber, the circles drawn in a heavy line represent the actual infra-red lamps, and the circles drawn in lighter continuous lines represent just some of the images of the lamps formed by reflection in the walls. Clearly the images themselves will give rise to further reflcted images extending in every direction so that the configuration of lamps themselves and all their images formed by reflection in the chamber walls is substantially larger than the body to be heated and approximates to an array of infinite size. It is noted that, for the sake of clarity, the quartz sleeve—which anyhow is transparent to the radiation emitted by the lamps—is not shown in this Figure.

It has been found that this arrangement enables a semiconductor wafer to be heated rapidly and with a surprisingly high degree of uniformity over the whole wafer. For example Figure 4 shows some results obtained for a semiconductor wafer having a diameter of approximately 100 mm. and a thickness of 0.5 mm. using a furnace substantially as described above. Figure 4 is a graph showing on the vertical axis the temperature of the semiconductor wafer and on the horizontal axis the furnace-on time. From this graph it can be seen that a 100 mm. wafer can be heated to at temperature of 1000°C in as little as 9 seconds, to 1060°C in 10 seconds and to 1100°C in only 13.5 seconds. Not only are such temperatures reached remarkably quickly but the wafer temperature also falls quickly when the lamps are switched off. Thus the wafer need spend only a short time at the maximum temperature thereby minizing dopant redistribution. Morever, the temperature uniformity across the wafer was found to be as high as 99%.

Figure 5 shows some actual results obtained by the Applicants using the furnace described here to anneal 100 mm.-diameter wafers implanted with a range of dopants. In Figure 5 the sheet resistance (in ohms per square) is plotted on the vertical axis against the furnace-on time (in seconds) on the horizontal axis. The solid line with solid circular points represents a boron implant at 40 keV, the broken line with the open circular points represents an arsenic implant at 180 keV, and the chain line with triangular points represents a phosphorus implant at 100 keV. Results are shown for all implants at doses of 2×10^{14}, 5×10^{14}, 1×10^{15}, 2×10^{15} ions cm^{-2} and for arsenic at 5×10^{15} ions cm^{-2}. It is evident that in most cases full electrical activation is achieved within only a few seconds and in all cases in under approximately 11 seconds.

In the furnace arrangement described above the first set of heat lamps 7 was in registration with the second set of lamps 15 when viewed in the direction from the top wall 1 to the bottom wall 2 of the chamber. As shown in Figure 3 this gives rise to a regular infinite array of lamps and their reflected images. However, under some circumstances it may be preferable to establish an irregular array, for example, in order to avoid localized hot-spots on the wafer. Thus in another arrangement the lamps 15 of the second set, when viewed in that same direction, may be present at locations intermediate the lamps 7 of the first set.

Finally, it is noted that the embodiment described above is merely exemplary and it will be evident to the person skilled in the art that many modifications are possible within the scope of the invention. Also it is noted that a furnace in accordance with the invention may be used for heating bodies other than semiconductor wafers although it is suited especially to that particular application.

CLAIMS

1. A furnace comprising a chamber for receiving a body to be heated, and a plurality of heat radiation lamps for heating said body, characterized in that the chamber has reflecting walls, and in that the lamps are so arranged inside the chamber with respect to the walls that the configuration of lamps and their images formed by reflection in said walls approximates to an array of infinite size.

2. A furnace as claimed in Claim 1, characterized in that the area occupied by the lamps is at least as extensive as the body to be heated.

3. A furnace as claimed in Claim 1 or Claim 2, characterized in that the spacing between

adjacent lamps is less than the spacing between the lamps and the location in the chamber of the body to be heated.

4. A furnace as claimed in any of the preceding Claims, characterized in that the chamber is substantially rectangular and has plane reflecting walls.

5. A furance as claimed in any of the preceding Claims, characterized in that the furnace comprises a first set of heat radiation lamps each at substantially the same distance from a first wall of the chamber.

6. A furance as claimed in Claim 5, characterized in that the furnace comprises a second set of heat radiation lamps in which second set each lamp is at substantially the same distance from a second opposite wall of the chamber.

7. A furnace as claimed in Claim 6, characterized in that the first and second sets of lamps are arranged in respective first and second planes parallel to the first and second walls of the chamber, and in that said first and second planes are equally spaced from a plane midway between and parallel to said first and second walls.

8. A furance as claimed in Claim 6 or Claim 7, characterized in that, viewed in the direction from the first wall to the second wall, the lamps of the second set are present at locations intermediate the lamps of the first set.

9. A furnace as claimed in any of Claims 6 to 8, characterized in that the lamps in each set are substantially equally spaced from each other.

10. A furance as claimed in any of the preceding Claims, characterized in that the lamps are mutually parallel straight filament lamps.

11. A furnace as claimed in any of the preceding Claims, characterized in that the lamps extend through apertures in two opposite walls of the chamber.

12. A furance as claimed in Claim 11, characterized in that the apertures are larger in diameter than the lamps.

13. A furnace as claimed in Claim 12, characterized in that the apertures communicate with ducting means for providing a cooling atmosphere for the lamps in the chamber.

14. A furnace as claimed in Claim 13, characterized in that the chamber contains an open-ended sleeve for shielding the body to be heated from the cooling atmosphere, which sleeve is transparent to the heat radiation from the lamps.

15. A furnace as claimed in Claim 14, characterized in that the chamber comprises a reflecting wall portion which forms a removable end stop for the sleeve.

17. A furnace as claimed in Claim 16, characterized in that the removable end stop fits slideably within the transparent sleeve.

18. A furance substantially as herein described with reference to Figures 1 and 3 of the accompanying drawings.

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