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(54) Electric heaters

(57) A thick film electric heater 1 comprises an insulating substrate 5 provided with a thick film resistive heating track 7. The resistive track 7 comprises at least two discrete sections connected by a bridge 11 of a material having a resistivity lower than that of the resistive track, such as silver.

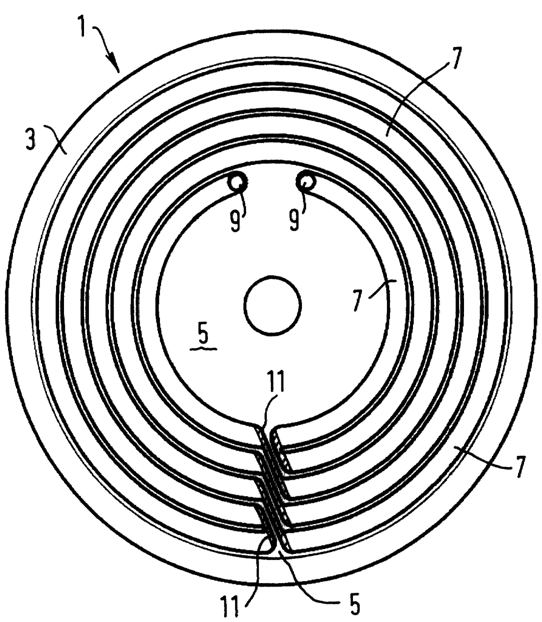

FIG. 1.

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Description

[0001] The present invention relates to thick film electric heaters comprising an electrically resistive thick film heating track applied to an electrically insulating substrate, and in particular to such electric heaters for use in liquid heating vessels. Examples of such heaters are described in WO96/18331 and WO96/17496.

[0002] In order to manufacture a heater at the lowest possible cost, it is important to design the track layout so that best use of materials is made. The overall resistance of the track is determined by the track material and the width and length of the track. For a given operating voltage, the power output of the track is determined by its resistance and the "micro" power density (ie that of the track itself)of the track determined by the width and length of the track.

[0003] However, the track does not cover the whole insulating substrate, since, for example, spacing must be provided between the individual sections of track. Accordingly, the "macro" power density of the whole heater (over the area covered by the insulating layer) will be significantly less than the power density of just the track. The ratio of these two power densities gives an indication of the amount of wasted space, and therefore wasted materials, used in the manufacture of a heater. In existing heater designs, the ratio is less than 60%.

[0004] In general, it is required that the power output of the heater is set at a certain value e.g. 3kW at a certain density e.g. $50Wcm^{-2}$, the resistance of the track material then determines the length and width of the track required. The product of length and width of the track gives the micro power density whilst the length divided by width determines the power. Ideally the track layout is made as compact as possible in order to reduce the material wastage, but still meeting the required power output and maximum micro power density of the track. However, the design of a compact track layout is restricted by a phenomenon known as "current crowding". According to this phenomenon, current tends to take the path of least resistance around the inside of bends in the track. This is particularly significant in tight bends where current build-up will result in excessive heating of the track on the inside of the bend to the extent that the track may fail.

[0005] Accordingly in existing designs, as exemplified in WO96/17496, adjacent wide resistive tracks are joined by high radius loops of track to avoid current crowding. However this leads to large areas of the substrate in the region of the loops not being covered by track, resulting in a reduction of the overall macro power density of the heater.

[0006] An alternative approach has been to use multiple narrow tracks where the effect of current crowding is less significant. The tracks are arranged electrically in parallel so as to have an overall width equivalent to a single track of the requisite width. However, it will be appreciated that a set spacing needs to be left between adjacent tracks for electrical insulation purposes and also to reduce cross-heating between tracks. Accordingly, if multiple tracks are provided in parallel considerable space is wasted due to the space between these adjacent parallel tracks. Again this reduces the overall macro power density of the heater.

[0007] Thus in order to increase the total macro power density of the heater it is desirable for the track to be as wide as possible, because each track must be separated from any adjacent track to prevent electrical connection and/or arcing. Thus, the wider the track the fewer the number of turns of track required to cover the entire insulated substrate and the number of spaces between the tracks, resulting in a lower wastage of space. However to achieve this, a way must be found of overcoming the problem of current crowding occurring in the track between adjacent turns of the track.

[0008] Furthermore the heater may have obstacles which must be avoided by the resistive track, for example contact pads or mounting locations for a control unit. The avoidance of such obstacles produces space on the substrate and also therefore reduces the overall density of the heater.

[0009] According to an invention disclosed herein there is provided a thick film electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein the resistive track comprises at least two discrete sections connected by a bridge of material having a resistivity lower than that of the resistive track.

[0010] Thus, by means of the invention, bends of high curvature may be avoided in producing a compact track layout because such bends may be replaced by bridges. Furthermore, bridges may be used to circumvent obstacles on the heater. The high conductivity of the bridges prevents or substantially reduces the effect of current crowding around any bends in the bridges, as the difference in resistance from the inner to the outer edge of a bend in this material is less marked. Accordingly, if required a much tighter radius of conductive track may be used which may be particularly important where such bridges are used to circumvent obstacles. The replacement of high radius loops connecting track sections makes possible a more compact track arrangement, meaning that a higher macro power density for the heater may be achieved, which means for a given power output, the heater may be smaller, thereby saving significant material costs, both in terms of the metal support plate, heating track and insulating layer materials.

[0011] Furthermore, and preferably, the bridges may be much narrower than the resistive track and can thereby maintain a micro power density close to that of the resistive track while using little space on the substrate. For example, if a material having a resistivity of about 0.1 that of the track material is used, it may be made 0.1 the width of the track while maintaining the same power density.

[0012] To minimise the amounts of bridging material used, preferably the bridge is substantially linear, most preferably of substantially constant width. Of course other bridge shapes may be used as appropriate. The bridge may be rectilinear if for example, it is joining the ends of two parallel tracks, or be curvilinear if, say, avoiding an obstacle.

[0013] Preferably the bridge extends completely across the width of a track section to ensure even flow of current into the bridge. Most preferably, the bridge extends perpendicularly across the track section.

[0014] Preferably, the resistive track comprises at least two parallel track sections connected at respective extremities by a conductive bridge. Various track arrangements may be envisaged and will depend to some extent on the shape of the heater plate or substrate. For example the track may be laid out as a series of parallel straight sections with the ends of adjacent sections joined. This may be particularly suitable for square or rectangular heaters. In an alternative arrangement, two parallel nested spirals of resistive track may be provided on the substrate.

[0015] In the case of a circular substrate having a double spiral track thereon, it is inevitable that a portion of the insulated layer will be left without coverage by the resistive track in the region of the outer end of the spiral. Advantageously, according to the invention, both the inner and outer tracks of the double spiral may be made to extend substantially to the outer edge of the heater substrate and the two ends may be connected by one or more conductive bridges. In this way, the coverage of the spiral track may be extended as far as possible towards the outer periphery of the substrate, as the need for a bend in this region is avoided.

[0016] In a preferred embodiment, however, the resistive tracks are in the form of concentric C-shaped rings. For maximum coverage, each ring may extend substantially through 360°, leaving just sufficient space between the ends for insulation, and for bridges to be formed. The ends of the rings may be pairwise interconnected by bridges such that a continuous electrical path is formed. This is particularly advantageous when used on circular heaters. A central region of the heater may be left without tracks, for example to accommodate a temperature sensing sump in the heater as disclosed in WO97/04694. This untracked region can be relatively small being limited only by current crowding considerations.

[0017] In one embodiment, the track is of substantially constant width. To give a desired power output, the total length and area of the track can be calculated. It has been found that to produce a heating power of 3kW and a micro power density of about $50Wcm^{-2}$ using standard track material having a resistance of 0.1Ω per square, the track should be about 5.7mm wide with a length of about 1000mm.

[0018] The adjacent ends of adjacent rings may be joined together by the bridges, so that the current direction changes from track section to track section. In another arrangement, opposite ends of alternate rings are joined together by the bridges. This produces a track effectively with the form of a spiral hairpin, and allows the terminal portions of the track to be positioned close to one another, which is advantageous, for example where a high voltage drop is required between these portions to facilitate a controlled failure by the mechanism described in WO97/39603.

[0019] As mentioned above, present track film heaters have a ratio of macro to micro power density of less than 60% covered by heating track. The present invention allows much higher ratios to be achieved, for example over 70% or even 80% to 85%. From a yet further aspect therefore the invention provides a track film heater having over 70% and preferably over 80% of its insulated area covered by heating track.

[0020] Advantageously, one or more contacts for connection to the resistive track may be provided in the centre of the heater. As explained above in the case of, for example circular, heaters resistive tracks cannot be provided in the centre of the heater as the curvature of the tracks becomes too great and current crowding causes over-specification heating. Thus, at least some space must be left in the centre of the heater and a compact design is achieved by mounting any necessary controls for the element in this centre portion. The conductive bridge may be arranged to connect more than two track sections, For example, the bridge may form an electrical branch, or may connect two or more sections in parallel.

[0021] The provision of a pair of contacts in a central region of a track film heater is itself a novel arrangement, so from a yet further aspect, the invention provides a track film heater comprising a pair of electrical contacts arranged in the central region of the heater. Preferably, for a circular heater, the contacts are arranged within an area defined by a radius about half, and more preferably about one third, the radius of the insulating substrate.

[0022] The conductive bridges may be formed as printed sections of ink comprising a high proportion of conductive material, such as silver. Such inks are presently used, for example, to produce terminals for the tracks, and if the same ink is used for both purposes, it may be applied in a single printing operation.

[0023] Although as stated above, the track may use a constant track width, it has been found that particularly on dry switch-on of an electric heater of a liquid heating vessel the peripheral regions of the resistive track, are cooled by the adjacent material of the substrate and the surrounding atmosphere. Thus these regions of the track do not develop as high a temperature as those tracks which are completely surrounded by other tracks. It is desirable to obtain uniform heating across the whole of the element, particularly in dry switch-on conditions so that a thermally sensitive actuator may be positioned anywhere on the heater to obtain consistent operating temperatures.

[0024] According to an invention disclosed herein there is provided an electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein the resistive track comprises a plurality of adjacent track portions, the width of each track portion in a chosen region of the heater being such that the temperature profile across adjacent track portions is substantially constant.

[0025] Thus, in general, the track portions towards the edges of a track pattern, may be made narrower than the track portions towards the centre of the pattern. In this way, more heat will be generated by these track portions compared to the other track portions of the heater such that the loss of heat to the surrounding substrate will be compensated.

[0026] Thus in broad terms the invention provides an electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein the resistive track comprises a plurality of adjacent track portions arranged in a predetermined configuration, the width of a track portion towards the edges of the configuration being narrower than that of a track portion towards the centre of the configuration.

[0027] Of particular advantage in this case is an arrangement of concentric C-shaped tracks, as described above, as the width of each C-shaped track may be uniquely defined with regard to its position on the heater. Thus in a particularly preferred embodiment, the heater comprises a series of concentric C-shaped tracks, the radially outermost and innermost track(s) being narrower than the radially more central track(s). The amount of narrowing and widening may be determined empirically. Of course, with conventional tracks it is also possible to allow the track to taper or widen to obtain the same effect.

[0028] As stated above, it is normal for thermally sensitive actuators, such as bimetallic actuators, to be positioned against the heating tracks of a heater in order to control the operation of the heater. For example, a bimetallic actuator may be used to prevent the heater overheating. It has been proposed, in our United Kingdom Patent Application No. 9621977.9, that in order to use standard bimetallic actuators in such controls, it may be desirable to reduce the track power density and the temperature of the portion of the resistive track underneath the actuator by widening this portion of the track. However, such widening of the track requires additional space on the heater, not just for the wide track portion itself but also around the widened portion which must be accommodated by the adjacent tracks. Furthermore, the heater track material is expensive, which means that a wider track increases material costs.

[0029] According to an invention disclosed herein there is provided a method of reducing the power density of a portion of thick film resistive heating track, wherein a plurality of sections of conductive material are applied over or under the portion of track, so as partially to cover the track portion.

[0030] This invention also extends to an electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein a portion of the heating track is overlaid or underlaid with a plurality of sections of conductive material partially covering the portion of track.

[0031] The conductive material applied over or under the resistive heating track effectively short circuits small regions of the track portion thereby reducing the total resistance of that portion of the track. This reduces its micro power density and its operating temperature. It has the advantage, however, that the track width does not need to be increased to achieve the reduction thereby reducing wastage of space on the heater and reducing material costs.

[0032] The conductive material may be, for example, a silver ink as described above. Preferably, the plurality of conductive sections are applied in a speckled, spotted or dashed pattern such that only a small amount of conductive material is required to achieve a region of lower resistance, thereby saving on the cost of materials.

[0033] The particular pattern and degree of coverage required to produce a desired temperature may be determined empirically.

[0034] Some embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of a first embodiment of the present invention;
Figure 2 is a schematic view of an alternative arrangement of the embodiment of Figure 1;
Figure 3 is a schematic view of a second embodiment of the present invention;
Figure 4 is a schematic view of a third embodiment of the present invention;
Figure 5 is a schematic view of a fourth embodiment of the present invention;
Figure 6 is a detailed view of the embodiment of Figure 5;
Figure 7 is a partial schematic view of a feature of a fifth embodiment of the present invention; and
Figure 8 is a schematic view of a further embodiment of the invention.

[0035] In the Figures, like reference numerals are accorded to corresponding elements of the various embodiments.

[0036] Figure 1 shows an electric thick film heater 1 comprising a stainless steel plate 3 on which is provided an insulating layer of glass, glass ceramic or ceramic 5 , eg Dupont 3500. On top of this insulating layer 5 are printed a number of C-shaped resistive thick film heating tracks 7. Each of the four outermost tracks 7 extends around substantially 360°, with opposed ends being separated only by a relatively small gap, in the order of 1.5-2mm. The heating tracks 7 are applied to the insulating layer 5 by printing of suitable metal loaded inks such as Dupont 3642/45 mixture, in a manner well known in the art.

[0037] The innermost heating tracks 7 of the heater 1 are provided at one end thereof with terminal portions or contacts 9 for connection to a power supply via a suitable control mechanism (not shown) for example as shown in our co-pending application filed on the same day and entitled "Thick Film Heaters". In that application, a contact member is bonded to the track by positioning the contact on top of a contact receiving pad of material such as Dupont 7760 and then fired to bond the contact in position.

[0038] The C-shaped resistive heating tracks 7 are interconnected by conductive bridges 11 which are printed over or under the ends of tracks and are in electrical connection therewith. The arrangement of the bridges 11 is such that the overall heating track including the resistive heating tracks 7 and the silver bridge 11 forms a continuous electrical path from one terminal portion 9 to the other terminal portion 9.

[0039] The advantage of this arrangement over prior art track layouts is that the bridges 11 replace the sections of the resistive heating track that would require tight turns in the heating track. The temperature of the heating track at such tight bends tends to increase on the inside of the bend because of current crowding.

[0040] As stated above, the resistivity of the bridge material is lower than that of the track 7. The bridge material may, most conveniently comprise a silver material, such as that presently used in printing contact pads onto the heater. This has the additional advantage that contact pads or contact receiving pads may be printed on the terminals 9 of the track at the same time as the bridges 11. Such materials are well known in the art, one, for example, being Dupont 7760 mentioned above.

[0041] Such conductive materials may have a resistivity very much lower than the track materials, for example .1 or even as low as .025 that of the typical track material. Theoretically, therefore, to maintain a constant power density in the track 7, the bridge 11 may be very much narrower than the track, for example of the same order of the ratio of resistivities. However, such a narrow track may not be reliably printable to ensure proper alignment and contact with the tracks, so in the embodiment shown, the bridges 11 are about 1mm wide, overlapping the ends of the track sections by about .5mm.

[0042] In the arrangement of Figure 1 the internal diameter of the innermost track 1 is 46mm and the external diameter of the outermost track 7 is 94mm. The tracks each have a width of 4mm and are spaced by 1mm. The contacts 9 are arranged on a radius which is just inside one half the radius of the insulated area of the heater.

[0043] Figure 2 shows an alternative arrangement of the embodiment of Figure 1 in which the terminal portions 9 are located on the second innermost track 7. It is clear from this embodiment that the terminals may be located on any of the C-shaped tracks, depending on the mounting requirements of the heater and associated controls. However, in the present case it is preferred that the terminal portions 9 are mounted in the region of the centre of the heater such that a control device for the heater may be mounted in the centre of the plate 3, as in this area the radius of the resistive tracks would be so small that current crowding would occur.

[0044] Figure 3 shows a further track layout according to an embodiment of the invention. In this case, the C-shaped resistive tracks 7 are joined in pairs by silver bridges 11. From the live terminal 9a the current path follows a circular course until it reaches a first silver bridge 11. At this point it crosses onto the next C-shaped track 7 and reverses direction to follow a further circular path. This continues similarly until the outermost resistive track 7 is reached. The outermost resistive track 7 is connected to the innermost resistive track 7 by a longer silver bridge 11a. The innermost resistive track 7 is connected by a further silver bridge 11 to the neutral terminal 9b. It is thought that constant reversal of current direction may reduce EMF emissions.

[0045] Figure 4 shows a further embodiment of the invention in which the arrangement of the tracks 7a to 7f and the silver bridges 11 on an insulated substrate 5 corresponds substantially to that of Figure 1. However, in this embodiment, the internal radius of the innermost track 7a is 9.87mm and the external radius of the outermost track 7f is 46.57mm. The tracks are spaced by 0.5mm. The track is designed to produce a power output of 3kW. To produce this output using a constant width of track, a track length of 1000 mm and a track material having a resistivity of 0.1Ω per square would require a track width of 5.7mm. However, in this embodiment the tracks vary in their widths from the centre of the heater to the outer periphery as shown in the following table.

Track	Width (mm)
7a	5.13
7b	5.70
7c	6.27
7d	6.27
7e	5.70
7f	5.13

Thus, the widths of the tracks 7b and 7e have been set at 5.70mm and widths of the adjacent tracks increased and decreased by 10% respectively. Due to their narrower width the resistance per unit length of tracks 7a and 7f is higher than the resistance per unit length of tracks 7c and 7d. The losses to the edge or the centre of the heater from tracks 7f and 7a, which are not completely surrounded by adjacent tracks, are greater than those for the central tracks 7c and 7d such that the greater power output per unit area of tracks 7a and 7f is compensated by the increased loss to atmosphere of these tracks. The variation of the track width therefore ensures that a more constant temperature profile is maintained across a radius of the heater 1.

[0046] In this embodiment assuming the insulating substrate 5 has an inner radius of 7.5mm and an outer radius of 48.94mm the total insulated area of the heater is about 7350mm^2. The actual track area is about 5860mm^2, which means that about 80% of the insulated surface of the heater is covered by track, i.e. the heater has a ratio of macro to micro power density of 0.8.

[0047] Also, the contacts 9 are arranged on a radius of about one third the radius of the insulated heater area.

[0048] Figure 5 shows a further embodiment of the present invention in which two distinct groups of tracks are provided on the heater 1. Such an arrangement might be used, for example, in airpots where a high power section of track and a lower power section of track may be selectively energised. Such an airpot is disclosed in WO 97/04694. A first set of outer tracks 7a (width 1.2mm) are provided and are connected at adjacent ends by silver bridges 11a in the configuration described in relation to Figure 3. A second set of inner tracks 7b (width 3.4mm) are also connected at respective end portion by silver bridges 11b. Electrical connections are made to the tracks 7, specifically at a line terminal 9a, an intermediate terminal 9b and a neutral terminal 9c.

[0049] The track section 7a has a resistance of about 490Ω and section 7b a resistance of about 90Ω such that when a supply is connected across terminal 9b and 9c, 600W will be generated. This would be sufficient to boil liquid in a vessel. However when a supply is connected across terminals 9a and 9c, only 100W will be generated, which is sufficient, for example to simmer boiled liquid.

[0050] Figure 6 shows detail of the outer track 7a and silver bridges 11a of the track layout of Figure 5.

[0051] Figure 7 shows, in scrap view, a feature of a fifth embodiment of the present invention in which the silver bridges 11 are used to create a conductive path around obstacles on the surface of the substrate. The heater track 7 is broken around obstacle 13 which may be, for example, a connecting boss for a control for the heater, but electrical connection between the broken portions of the track 7 is made by silver bridge 11. In this way, the obstacle 13 may be avoided without the wide turns of the track 7 that are required in conventional heater.

[0052] Figure 8 shows a detail of a further embodiment of the invention. In this embodiment, a section of track 7 is overprinted or underprinted with a pattern 8 of a conductive material such as the silver ink Dupont 7760 referred to above. The lengths of conductive material act to short out small sections of the track thereby reducing its micro power density and resistance.

[0053] Where the track has silver bridges and/or contact pads of the same material they can all be printed at the same time. Accordingly, it is preferred that the pattern is printed over the track 7.

[0054] Other patterns of conductive material may be used, such as bands running across the track, spots of material arranged on the track material and so on.

[0055] The present invention deals generally with the provision of economical and efficient track layouts. The techniques required to put the invention into effect are well known in the art.

Claims

1. A thick film electric heater comprising an insulating substrate provided with a thick film resistive heating track, having a plurality of portions comprising a material having a resistivity lower than that of the resistive track thereby reducing the power density of said portions of the track.

2. A heater as claimed in claim 1 wherein said lower resistivity material comprises a bridge connecting two discrete sections of said resistive track electrically in series.

3. A heater as claimed in claim 2, wherein the bridge is substantially linear.

4. A heater as claimed in claim 2 or 3, wherein the bridge is of substantially constant width.

5. A heater as claimed in claim 2, 3 or 4, wherein the bridge extends completely across the width of a track section.

6. A heater as claimed in any one of claims 2 to 5, wherein the bridge extends perpendicularly across the track section.

7. A heater as claimed in any one of claims 2 to 6, wherein the bridge is narrower than the track sections.

8. A heater as claimed in any preceding claim, wherein the resistive track comprises at least two parallel track sections connected at respective extremities by a conductive bridge.

9. A heater as claimed in any preceding claim, wherein the resistive track is in the form of concentric C-shaped rings.

10. A heater as claimed in claim 9, wherein the ends of the rings are pairwise interconnected by bridges of material having a resistivity lower than that of the resistive track such that a continuous electrical path is formed.

11. A heater as claimed in claim 10, wherein the adjacent ends of adjacent rings are connected by the

bridges.

12. A heater as claimed in claim 10, wherein opposite ends of alternate rings are joined together by the bridges.

13. A heater as claimed in any preceding claim, comprising track sections in the form of two nested spirals connected at an outer extremity by a conductive bridge.

14. A heater as claimed in any preceding claim, wherein at least one bridge of lower resistivity material is arranged to circumvent an obstacle on the insulating substrate.

15. A heater as claimed in any preceding claim, wherein one or more contacts for connection to the resistive track are provided in the centre of the heater.

16. A heater as claimed in any one of claims 2 to 15, wherein conductive bridges are formed as printed sections of ink comprising a high proportion of conductive material, such as silver.

17. A heater as claimed in any preceding claim wherein said lower resistivity material comprises a plurality of sections of conductive material partially covering a portion of the heating track.

18. A thick film heater having over 70%, and preferably over 80%, of its insulated area covered by heating track.

19. A thick film electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein the resistive track comprises at least two discrete sections connected by a bridge of material having a resistivity lower than that of the resistive track.

20. An electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein the resistive track comprises a plurality of adjacent track portions, the width of each track portion in a chosen region of the heater being such that the temperature profile across adjacent track portions is substantially constant.

21. An electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein the resistive track comprises a plurality of adjacent track portions arranged in a predetermined configuration, the width of a track portion towards the edges of the configuration being narrower than that of a track portion towards the centre of the configuration.

22. A heater as claimed in claim 21, wherein the heater comprises a series of concentric C-shaped tracks, the radially outermost and innermost track(s) being narrower than the radially more central track(s).

23. A method of reducing the power density of a portion of thick film resistive heating track, wherein a plurality of sections of conductive material are applied over or under the portion of track, so as partially to cover the track portion.

24. An electric heater comprising an insulating substrate provided with a thick film resistive heating track, wherein a portion of the heating track is overlaid or underlaid with a plurality of sections of conductive material partially covering the portion of track.

25. A heater or method as claimed in claim 17, 23 or 24, wherein the plurality of conductive sections are applied in a speckled, spotted or dashed pattern.

26. A heater or method as claimed in claim 17, 23 or 24, the conductive material comprises silver.

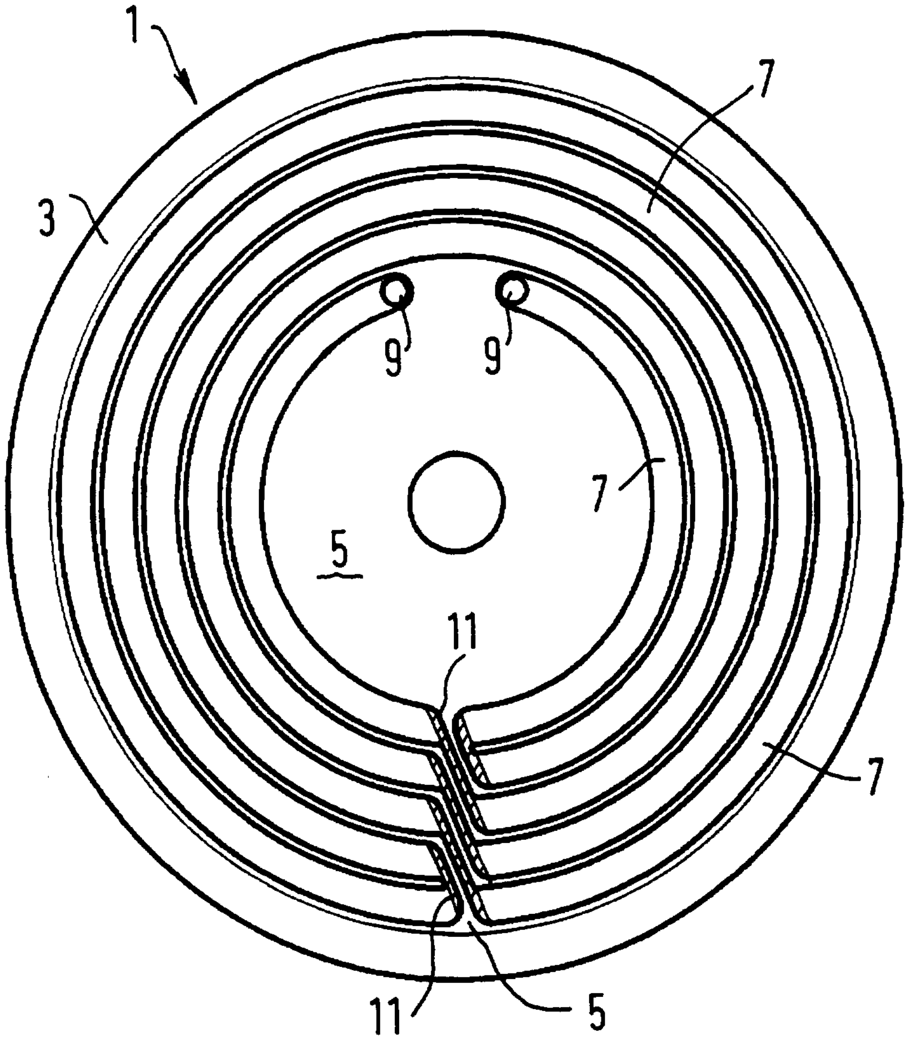

FIG. 1.

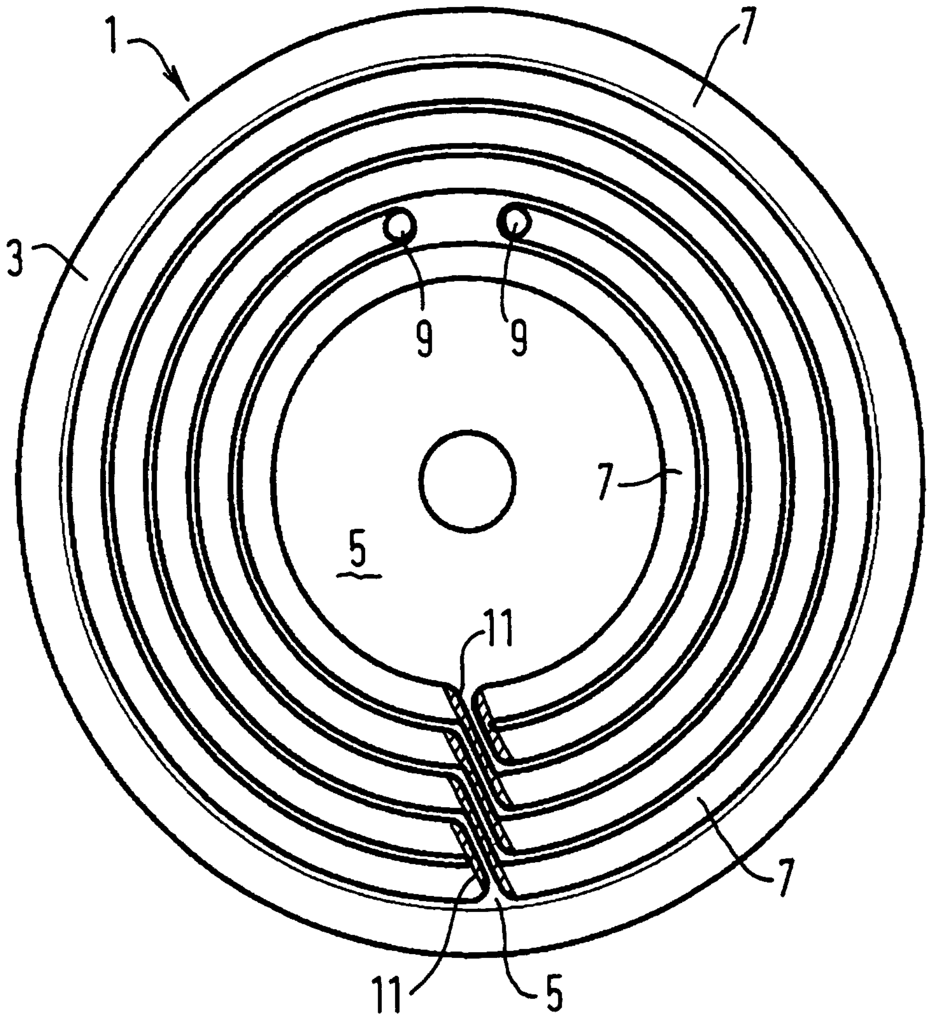

FIG. 2.

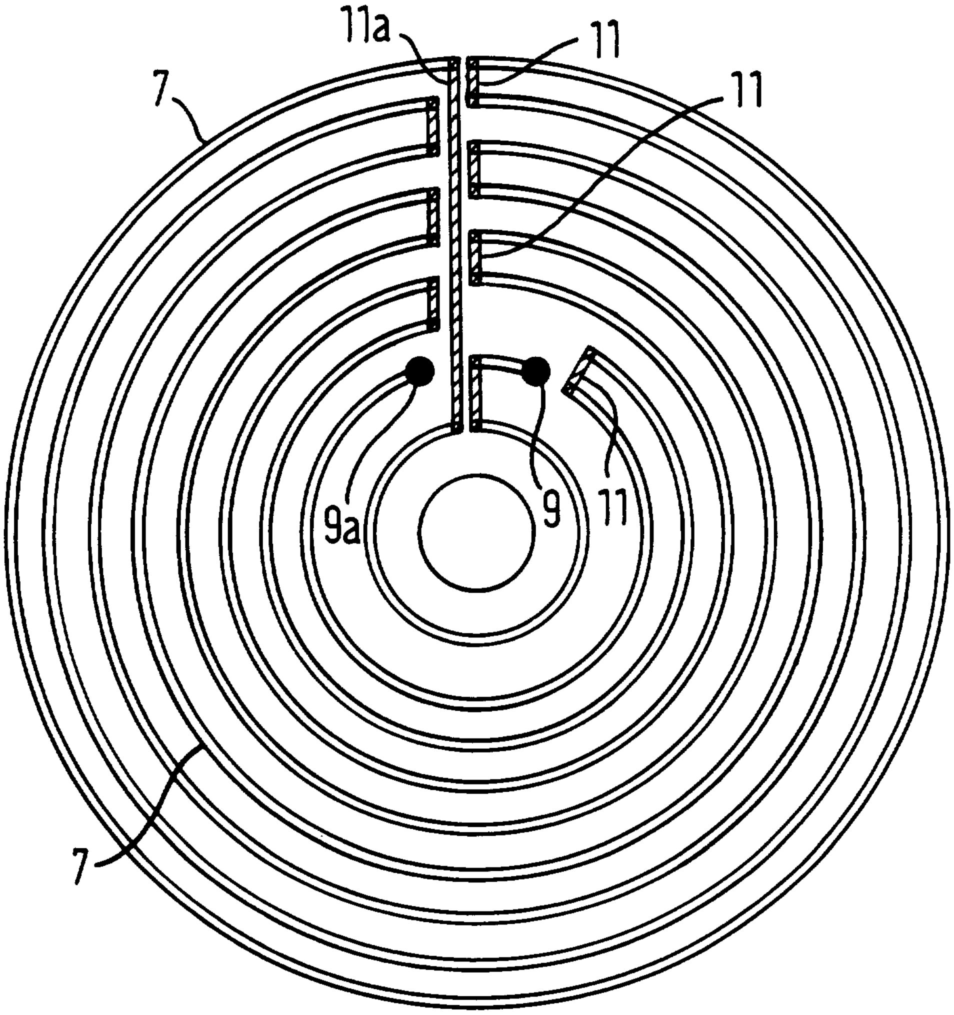

FIG. 3.

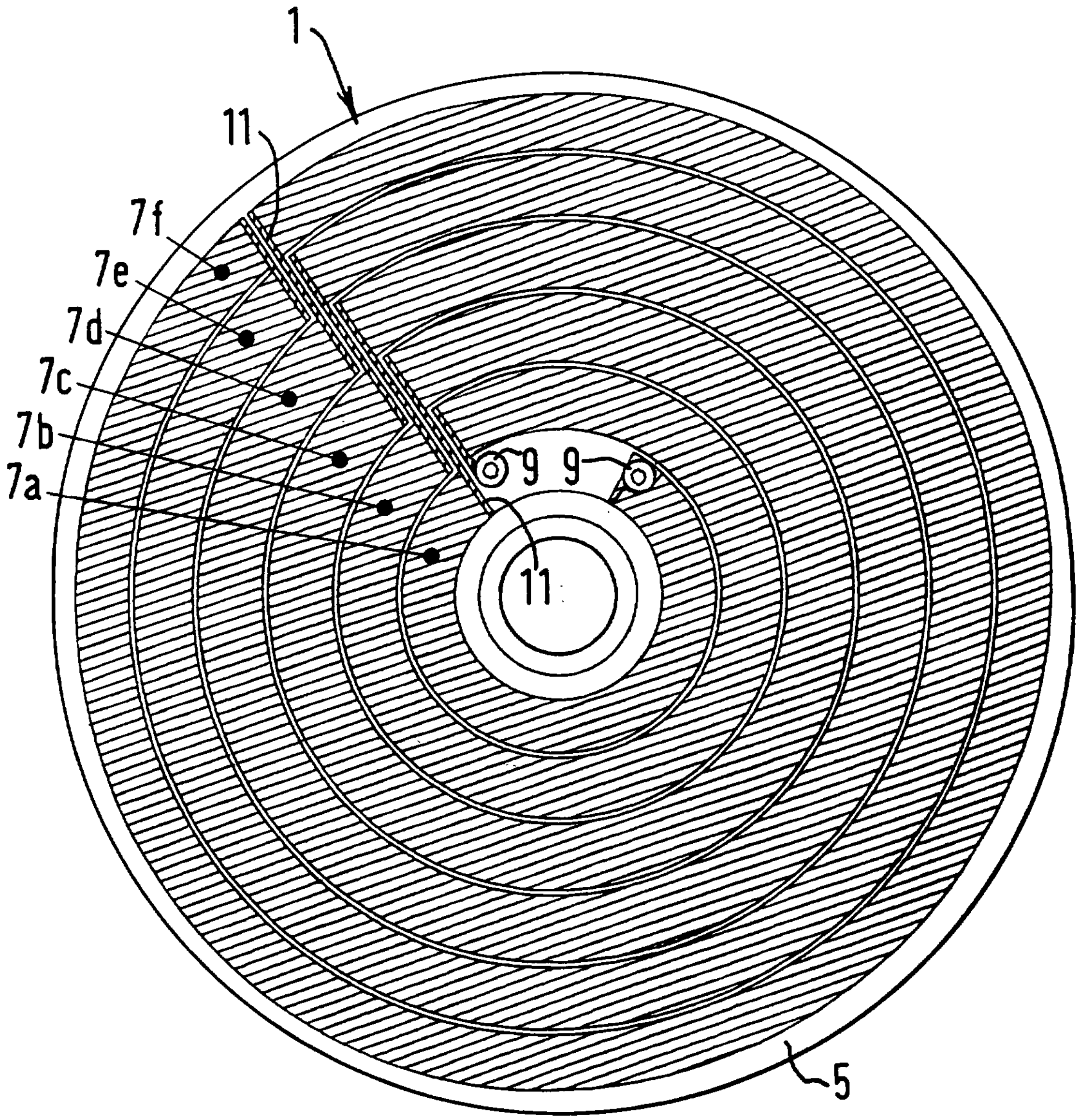

FIG. 4.

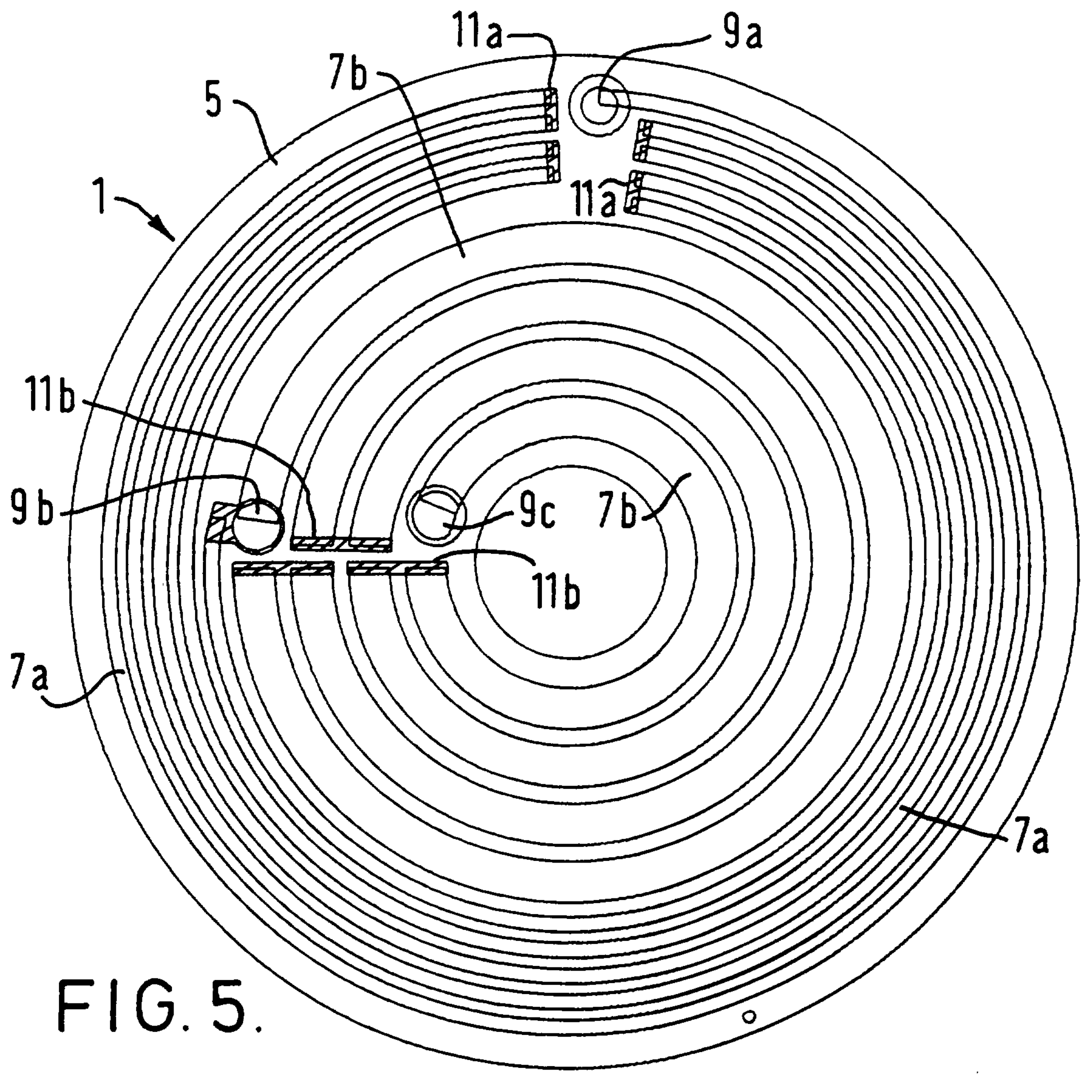

FIG. 5.

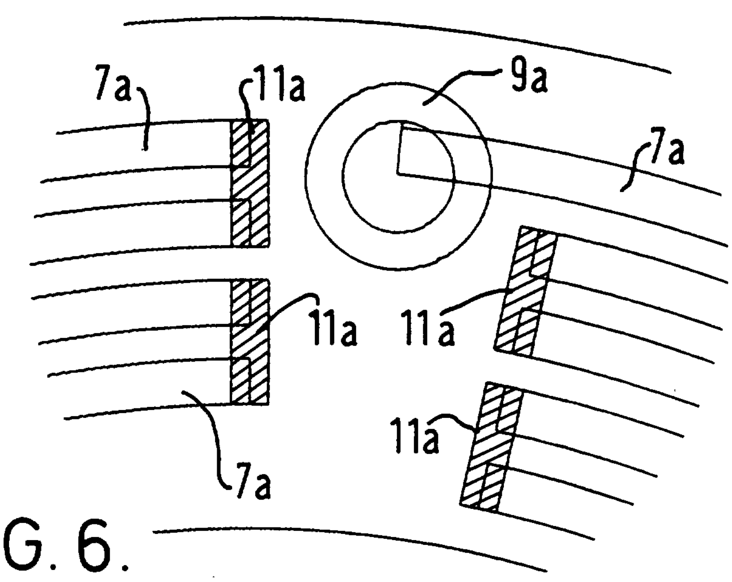

FIG. 6.

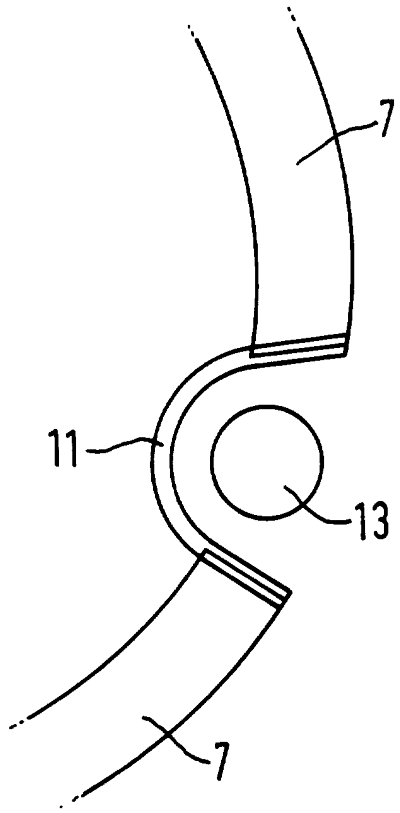

FIG. 7.

FIG. 8.