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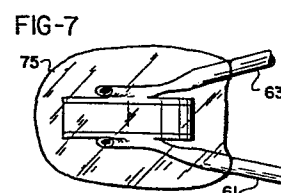
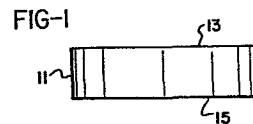
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54 Glass coated disk thermistor.

57 A tri-metal contact film (31, 33) of silver, platinum, and palladium is metallurgically bonded to the opposite surfaces of a disk (11) of dense, controlled temperature coefficient of resistance thermistor material. The disk is trimmed to the desired electrical dimensions and a silver-clad wire (61, 63) is fusion welded by thermal compression bonding to the contact film (31, 33) on each side of the disk. The method of making electrical contact allows the assembly to be encased in a conformal glass coating (75). The glass coating (75) provides an enhanced stability thermistor having predetermined characteristics.



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GLASS COATED DISK THERMISTOR .

The field of the invention is in the thermistor art and more particularly in the fabrication of highly stable disk thermistors having
5 predetermined resistance characteristics.

Thermistors are well known electrical devices that exhibit a wide change in resistance values with changes in temperature. Generally, they
10 are made by sintering mixtures of metallic oxides such as oxides of cobalt, copper, iron, manganese, nickel, and uranium. These mixtures are formed into various shapes, such as beads, disks, probes, rods, and washers. Two very common forms are (1) beads,
15 because they are generally very stable in difficult environments and (2) disk, because they can readily be fabricated and trimmed to provide a predetermined resistance-temperature characteristics, thus interchangeable disk units are readily produced. The
20 bead units are generally fabricated by imbedding lead wires in the bulk thermistor material such as by placing a drop of the thermistor suspension on two lead wires. The entire package is glass coated by applying a drop of glass-liquid suspension over
25 the dried thermistor drop and vitrifying the unit in a high-temperature furnace. The beads thus formed vary not only in size and in compactness of the thermistor material, but also in electrical characteristics. The glass bead structure provides a
30 compact unit that is generally impervious to moisture and other gases and fluids. They will withstand relatively high temperatures, and have firmly anchored leads. A problem with glass coated bead thermistors is that in the present state of the art
35 there is no known method for trimming bead units, or precisely controlling their temperature coefficient

of electrical resistivity. Thus, mass production of a quantity of units having even a reasonable percentage of controlled interchangeability is not presently possible.

5 On the other hand, disk units, including those with holes through them, i.e., washers, may readily be fabricated under very controlled conditions of uniform size, uniform compacting pressures, uniform firing temperatures, and with a very important feature of being readily cut or trimmed to a specific value of resistance. Contact with the thermistor material is generally made through a sprayed-on glass-silver film. The film does not make a metallurgical bond to the thermistor. The bond is more of a contact or pressure-type bond, wherein the glass forms a porous matrix which fuses to the thermistor. This matrix holds the interstitial silver in contact with the thermistor. Firing the disk cements the silver to the disk of thermistor material. Silver-glass coating on the edge of the disk is removed by grinding, and the disk is further trimmed to produce the desired resistance. Copper lead wires are then soldered to the glass-silver mix that is adhering to the surface of the thermistor material. The assembly is then encased in an epoxy, and a precise unit having predetermined characteristics is provided. However, the epoxy overcoat is a low stiffness substance incapable of applying significant compressive force to the disk. It is also relatively permeable to gases and water vapor which can cause corrosion of the internal metallic elements. In addition, the upper temperature limit of suitable operation of the disk units is generally quite restricted compared to the glass-encased bead units. Generally, units fabricated with conventional solder connections are

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limited to approximately 150°C by the solder. Pressure contacts units, such as typically used in washer types, may be used to approximately 150°C. Units that are lacquer coated instead of epoxy are limited to approximately 100°C. Glass coated bead thermistors will generally operate and remain reasonably stable up to temperatures approaching 300°C, (600°C for short time periods for special bead types). The foregoing temperatures are generally short-term maximum operating temperatures and as such are not indicative of the long-term stability characteristics of the thermistor. It is the imperviousness of the encapsulant to contaminants over a relative lengthy period of time in a relatively moderate temperature and the compression of a conformal glass coating that primarily determines the factor of stability of a thermistor. While the fabrication of embodiments as taught herein does provide a disk thermistor having higher maximum operating temperatures than previous disk thermistors, the primary feature is the greatly improved stability of the disclosed units over the prior art devices.

Attempts have been made to encase disk-type units in a glass overcoat. This has not been successful for several reasons, the principal one being the previously mentioned fact that the glass-silver contact film does not make a metallurgical bond to the bulk thermistor but is more of a pressure-type contact and the reheating of this film to glass sealing temperatures alters its contact geometry and hence the previously determined resistance characteristics of the assembly. The advantage of providing a unit having predetermined characteristics is therefore lost. Thus, prior to this invention, a thermistor having the stability of

glass bead-type thermistors with the predetermined characteristics of disk-type thermistors has not been available. In the glass coated disk thermistor disclosed herein, the method of fabrication using a tri-metal contact film, and the thermo-compression bonded leads allows the bulk thermistor material to be both rigidly constrained and protected from ambient contaminants while maintaining the feature of providing controlled electrical characteristics.

Further information on the relative stabilities of state of the art bead and disk thermistors may be found in the paper, "An Investigation of the Stability of Thermistors" by Wood, Mangum, Filliben, and Tillett published in Journal of Research of the National Bureau of Standards, Vol. 83, No. 3, May-June 1978.

A glass coated disk thermistor and the method of fabrication are disclosed. The devices of the invention have the stability and environmental immunity of glass coated bead-type thermistors with the predictability of electrical characteristics found only in previous, relatively less stable disk-type thermistors.

According to one aspect of the present invention, a glass coated disk thermistor is provided comprising a disk of thermistor material having an upper surface and a lower surface with a film of a mixture of finely divided silver, platinum, and palladium metallurgically bonded to the upper and to the lower surface of said disk. A first wire lead having a silver surface is attached by fusion to the film on the disk's upper surface, and a second wire lead having a silver surface is attached by fusion to the film on the disk's lower surface. A conformally encapsulating glass coating encapsulates the film coated disk and the wire leads where the leads are attached to the film coated disk.

According to another aspect of the invention, there is provided a method of fabricating a stable disk thermistor having a predetermined resistance characteristic comprising the steps of
5 coating the flat surfaces of a disk of pressed thermistor material with a noble metal film containing finely divided silver, sintering the coating to the disk, measuring the resistance of the disk, removing a portion of said coated disk to provide
10 the predetermined resistance, welding leads containing silver to the coated flat surfaces, and fusing a conformal glass coating to the disk and leads.

It is thus an object of the present invention to provide a stable disk thermistor. It is
15 another object to provide a stable thermistor that may be adjusted during the fabrication to provide a unit having predetermined resistance versus temperature characteristics. It is another object to provide a disk thermistor suitable for operation in
20 relatively high temperatures. Finally, it is yet another object to provide a thermistor fabrication process providing interchangeable thermistors that have an intimate conformal glass coating.

In order that the invention may be more
25 readily understood, reference will now be made to the accompanying drawings, in which:

Fig. 1 is a schematic-pictorial elevational view of a pressed disk of thermistor material;

Fig. 2 is a corresponding schematic-pictorial
30 plan view of a pressed disk of thermistor material;

Fig. 3 is a schematic-pictorial elevational view showing a metal contact film positioned on the flat surfaces of the disk;

Fig. 4 is a schematic-pictorial representation of removing material from a coated, sintered
35 disk while monitoring its electrical resistance value;

Fig. 5 is a schematic-pictorial plan view of a coated, sintered disk, trimmed to a specific value of resistance;

5 Fig. 6 is a schematic-pictorial representation of fusion welding silver-clad lead wires to the coated thermistor disk by thermal-compression bonding; and

10 Fig. 7 is a schematic-pictorial elevational view of an embodiment of the invention illustrating a glass coated disk thermistor.

Generally, the knowledge of the composition of the bulk material from which to fabricate thermistors is in a well-defined art. In a typical thermistor, the principal materials are a mixture, in precise ratios, of nickel oxide and manganese oxide. The exact ratios of nickel oxide and manganese oxide plus well-known additives such as copper or iron to adjust the bulk resistivity and temperature coefficient to provide a desired type of characteristic are well known. The mixture containing the desired amounts of the constituents are typically ball milled and sift milled to accurately control the particle size of the mix. A uniform particle size also provides more uniform control of the coefficient of resistance of the material. Generally, an acrylic resin binder, as is conventionally used in the art, is added to the sized powder to give the pressed, unfired disk some strength so that it may be easily handled. After mixing in the resin, the mix is sift dried to break up any large clumps that might be present that might prevent uniform filling of the die. The powdered thermistor material is then compacted under high pressure to provide a mass that will have near theoretical density (generally well over 90%).

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Preferably, resinated powder is loaded into a conventional pill press-type die and under several thousand pounds per square inch of pressure, a high density thermistor pellet is formed. Alternatively, 5 disks of thermistor material may be cut or sliced from a relatively long cylindrical rod or sheet of previously prepared material. Typical sizes and embodiments fabricated as taught herein are approximately .090 inch diameter and .007 inch to .032 inch 10 thick. The portioning of sizes to provide a desired type of electrical characteristic is well known in the thermistor fabrication art. A pressed disk 11 of thermistor material after it is ejected from the die is schematically illustrated in elevation in Fig. 1 15 and in plan in Fig. 2. The physical shape of the thermistor is not critical. Generally, round disks with substantially flat and parallel surfaces are preferred. The invention is just as applicable to disks of square, rectangular or other shape cross 20 sections having two spaced electrical contacting areas.

After pressing, the flat surfaces 13 and 15 of the disk pellet are coated with an oxidation resistant material, preferably with a paste of 25 finely divided silver, platinum, and palladium in a conventional organic vehicle so that the flat surfaces are covered with a thick film. The ratios of these metals in the mixture are not critical, they do however, tailor the mixture's melting 30 temperature. The use of noble metals permit the firing in an oxidizing atmosphere which is compatible with the thermistor firing. The vehicle aids in the application of the paste. It, the vehicle, is not critical as it will burn away when fired. 35 Typical, suitable, conventional, ratios of metals for typical embodiments, such as being described,

are silver 54.55%, platinum 9.09%, and palladium 36.36%. An example of a suitable, commercially available well known organic vehicle is Terpeneol.

5 Coated disks are fired suspended in alumina powder in a ceramic boat. Generally, a plurality of disks are fired simultaneously. The disks are floated (suspended) in fine aluminum oxide powder in the boat to prevent their sticking to the boat or each other. It has been found desirable to first
10 heat the disks in the alumina powder to approximately 625°C at a rise time of 15°C per minute so that the acrylic resin and the coating vehicle are removed relatively slowly and that no violent out-gassing occurs which could rupture the thermistor.
15 It also prevents the carbonization of the organic materials. The boat, containing the thermistors after the preheat, is then transferred to a sintering furnace where it is preferably held at a temperature of approximately 1200°C for approximately
20 3 hours. This sinters the thermistor and adheres the metal coating to the bulk thermistor with a metallurgical bond. As is well known in the art, the temperature of the firing may be empirically adjusted to achieve a desired bulk temperature
25 coefficient for a particular ratio of thermistor materials. Typical sintering temperatures range from approximately 800°C to 1500°C with corresponding varying duration times.

The boat containing the fired thermistor
30 disks is removed from the furnace, and the thermistors are air-cooled to room temperature at a rate of approximately 200°C per second. This rapid cooling "freezes-in" the desired thermistor grain crystal lattice structure. A fired thermistor disk now
35 appears as illustrated in Fig. 3 with upper contacting film 31 on upper flat surface 13 and lower

contacting film 33 on lower flat surface 15. Typical film thicknesses range from approximately .0001 inch to .0005 inch. The thickness is not critical.

5 The disks each now have an ohmic resistance value between their parallel surfaces that at a specific temperature such as 25°C is a function of the disk material and the thickness and cross-sectional area of the disk. The relative temperature-resistance characteristic has substantially already
10 been determined by the choice of materials and the foregoing steps. To provide a unit having a predetermined resistance at a specific temperature, the coated thermistor material is cut to a size yielding
15 the desired resistance. Typically, thermistor material is removed from the edge of a disk of thermistor material. Obviously, only increases in the resistances of the disks as formed can be made. This is conventionally done as illustrated in
20 simplified schematic form in Fig. 4. The coated disk 41 is passed back and forth across the face of a rotating grinding stone 43, grinding a flat 45 on the edge of the disk 41. The electrical resistance of the disk is monitored as material is being
25 removed by conventional resistance measuring apparatus 47. Electrical contact is schematically shown as made with the disk through pressure contacting tabs 49 and 51. When the desired resistance is achieved, grinding is stopped and the disk is
30 removed from the grinding fixture. This step is generally termed "trimming the thermistor." Additional information on this well known step is contained in U. S. patent No. 2,970,411 to patentee Trolander. The disk now has the general appearance
35 as illustrated in Fig. 5. The electrical characteristics of the thermistor are now established and

further steps must not significantly alter the resistance level or temperature coefficient of the device.

5 Wire leads that will bond with the conductive coating on the surfaces of the disk are required for making electrical contact with the device. Silver or silver-clad wire leads are preferred. A suitable wire lead has been found to be approximately .006 inch diameter copper wire with a 100 micro-
10 inch silver coating. The end regions of the leads are prepared for attachment by cleaning and removing any insulation in the region of attachment and preferably flattening them slightly, so that an area of contact rather than a line contact is originally
15 made, and placing them on the coated surfaces of the disk. The amount of flattening is not critical. Generally, a flat approximately equal to or slightly greater than the radius of the wire is suitable. The flattened length should preferably be slightly
20 longer than the desired contact length with the conducting coating, but not so long as to extend beyond the glass coating in the final assembly. Flattening is not a requirement. Round wire may be used directly, as some flattening will occur normally
25 in the bonding process.

The coated, fired, and trimmed thermistor disk 41 with prepared wire leads 61 and 63 are positioned between the anvils 65 and 67 of a thermal-compression bonding fixture and heat and pressure
30 are applied. Generally, the leads are bonded to the central portion of the surfaces of the disk. If desired, the bonding may be located close to the edge. It is not critical.

In the embodiments being described, it has
35 been found that approximately a 600°C contact temperature provided by heating elements 69 and 71

with an anvil pressure 73 of approximately 5 ounces for approximately 10 seconds will fusion weld the silver coated wire leads to the tri-metal contact film. The thermo-compression welding temperature should be at least 460°C as this is the temperature at which silver oxide surface contaminants decompose to silver (metal) and oxygen (gas). In a particular embodiment such as being described in detail, the bonded wire to coating conducting area was over a contact length of approximately .050 inch and a width of approximately .003 inch. In equivalent metric dimensions, this is approximately equivalent to a pressure of 140 kilograms per square centimeter. The thermal-compression bonding technique provides a metallurgical weld of the wire to the film and avoids excessive heating of the thermistor material. It is to be noted that the step of trimming of the disk to a desired resistance value may take place after attaching the lead wires rather than before attaching them if desired.

After the welding of the wire leads to the coated surfaces of the disk, the disk and the wire leads, where attached to the disk and in the general area of the disk, are coated with a conventional low melting temperature glass frit mixed in a liquid binder. Generally, a disk is held by the lead wires and is dipped in the liquid. This is a convenient means of coating this assembly. The preferred glass frit has a melting temperature of approximately 500°C and a coefficient of thermal expansion closely matched to the disk and the leads. After coating, the frit paste is air dried to remove the binder. A suitable low-temperature glass frit is Owens-Illinois type SG-67. A suitable binder is water or Terpeneol. Generally, the dipped coating should be a "heavy" dipped coat with a thickness surrounding the disk that is at least the thickness of the disk.

The glass frit is fused to the disk and wire leads in a furnace at a temperature at approximately 500-600°C for 1 to 2 minutes. A shrinkage of approximately 20% of the glass coating is typical.

5 The time is kept relatively short to minimize the chance of a shift in the resistance or coefficient of resistance of the disk. A typical finished glass coated disk thermistor has the general appearance illustrated in Fig. 7. The glass coating 75 provides

10 a conformal glass coat completely encasing the thermistor disk and a portion of the wire leads 61 and 63 providing support and anchorage to the leads.

The use of a glass frit in forming a conformal glass coat over the thermistor is generally preferred, however, a suitable conformal glass coat may be obtained by the conventional dipping of the disk and lead wires in molten glass held at a temperature of approximately 600°C to approximately 700°C for approximately 3 to 10 seconds. Conventional flame sprayed glass may also be used to form the conformal glass coat.

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The stability of the glass coated disk thermistors fabricated as taught herein is approximately the same as that of conventional glass bead-type thermistors in the temperature range up to approximately 200°C. In addition to the greatly improved stability of the disclosed devices over the prior art disk-type devices, the maximum high temperature limit for trimmed disk thermistors is also appreciably extended.

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The average stability data from four early embodiments of the invention, each having a resistance of approximately 1200 ohms at 40°C, is as follows:

	<u>Hours of Aging at 150 degrees C</u>	<u>Apparent change in Indicated Temperature at 40°C from start of aging, in degrees C</u>
5	0	.000
	34	-.007
	57	-.011
	129	-.019
	274	-.017
10	498	-.029
	730	-.037
	820	-.045
	1017	-.039
	2285	-.052

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It is to be understood that specific
embodiments of the invention have been described in
great detail, but that the invention is not so
limited and that various changes in the details,
20 materials, steps, and arrangement of parts which
have been herein described and illustrated in order
to explain the nature of the invention, may be made
by those skilled in the art within the principle and
scope of the invention as defined in the appended
25 claims.

CLAIMS

1. A glass coated disk thermistor comprising:
a disk (11) of thermistor material having
an upper surface (13) and a lower surface (15);
a film (31, 33) of a mixture of finely
5 divided silver, platinum, and palladium metallur-
gically bonded to said upper surface (13) and to
said lower surface (15) of said disk (11);
a first wire lead (61) having a silver
surface;
10 a second wire lead (63) having a silver
surface;
means attaching in fusion relationship said
first wire lead (61) to said film (31) on the disk
upper surface (13) and attaching in fusion relation-
15 ship said second wire lead (63) to said film (33) on
the disk lower surface (15); and
a glass coating (75) conformally encapsul-
ating said film coated disk and said wire leads
where said leads are attached to said film-coated
20 disk.
2. The method of fabricating a thermistor
comprising the steps of:
compressing a powder mix of thermistor
material into a pellet (11) having at least two
5 spaced surface areas (13, 15);
coating two spaced surface areas (13, 15)
of said pellet with a metal paste (31, 33);
heating the coated pellet to sinter the
pellet and fuse the metal paste;
10 preparing leads (61, 63) with ends having
metal the same as in said metal paste;
contacting lead ends to coated areas of
said pellet;

15 applying heat and pressure to said lead
ends contacting the pellet thermo-compression
welding the lead ends to said coated areas of
pellet; and

fusing a conformal glass coat (75) to the
disk (11) and lead wires (61, 63).

3. A method as claimed in Claim 2, wherein said
powder mix comprises primarily an oxide of nickel
and an oxide of manganese.

4. A method as claimed in Claim 2, wherein said
metal paste is a thick film comprising finely
divided silver, platinum, and palladium.

5. A method as claimed in Claim 4, wherein said
leads have a silver surface.

6. A method as claimed in Claim 2, wherein said
fusing a conformal glass coating to the disk and to
the lead wire ends comprises coating the disk and
lead ends with a glass frit and fusing the glass
5 frit to the disk and lead wires at a temperature
between approximately 500°C and approximately 600°C
and for a time of approximately 1 to 2 minutes.

7. A method as claimed in Claim 2, wherein the
fusing a conformal glass coating to the disk and
lead wire ends comprises dipping said disk and lead
wire ends in molten glass at a temperature of
5 approximately 600°C to approximately 700°C for
approximately 3 seconds to approximately 10 seconds.

8. A method as claimed in Claim 2, wherein the fusing a conformal glass coating to the disk and lead wire ends comprises flame spraying glass over said disk and lead wire ends.

9. The method of fabricating a glass coated disk thermistor comprising the steps of:

compressing a resinated powder mix comprising primarily metallic oxides into a disk (11) having an upper surface (13) and a lower surface (15);

coating said upper surface (13) and said lower surface (15) of the disk with a thick film (31, 33) comprising finely divided silver, platinum, and palladium;

heating said film-coated disk to a temperature of approximately 625°C at a rise of approximately 15°C per minute;

sintering said fired, coated, disk at a temperature of approximately 1200°C for approximately 3 hours;

removing said disk from the sintering temperature and cooling said disk;

preparing an end region of a first (61) and of a second wire lead (63) each wire lead having a silver surface;

welding a portion of said end region of first wire lead (61) to said coated upper disk surface (31) and welding a portion of said end region of second wire lead (63) to said coated disk lower surface (33); and

fusing a conformal glass coat (75) to the coated disk and wire lead end regions.

10. A method as claimed in Claim 9, wherein said resinated powder mix comprises primarily nickel oxide and manganese oxide.

11. A method as claimed in Claim 10, wherein said cooling of the disk is at a rate of approximately 200°C per second.

12. A method as claimed in Claim 11, wherein said welding is a fusion formed by a contact temperature of approximately 600°C and a pressure of approximately 140 kilograms per square centimeter.

13. A method as claimed in Claim 12, wherein said finely divided silver, platinum, and palladium are in an organic vehicle.

14. A method as claimed in Claim 13, wherein the fusing of said conformal glass coat (75) comprises coating the coated disk and welded end regions of said wire leads with a low melting temperature glass frit and fusing said glass frit to the coated disk (11) and wire leads (61, 63) at a temperature between approximately 500°C and approximately 600°C for approximately one to approximately two minutes.

15. A method as claimed in Claim 13, wherein the fusing a conformal glass coating (75) to the disk and wire lead end regions comprises dipping said disk and lead wire end regions in molten glass at a temperature of approximately 600°C to approximately 700°C for approximately 3 seconds to approximately 10 seconds.

16. A method as claimed in Claim 13, wherein the fusing a conformal glass coating (75) to the disk and wire end regions comprises flame spraying glass over said disk and wire lead end regions.

17. The method of fabricating a stable disk thermistor having a predetermined resistance characteristic comprising the steps of:

- 5 coating the flat surfaces (13, 15) of a disk (11) of pressed thermistor material with a noble metal film (31, 33) containing finely divided silver;
- sintering said coating to said disk;
- measuring the resistance of said disk;
- 10 removing a portion of said coated disk to provide said predetermined resistance;
- welding leads (61, 63) containing silver to said coated flat surfaces (31, 33); and
- 15 fusing a conformal glass coating (75) to said disk and leads.

18. The method of fabricating a glass coated thermistor having a predetermined resistance characteristic comprising the steps of:

- 5 compressing a powder mix of thermistor material into a pellet (11) having at least two spaced surface areas (13, 15);
- coating two spaced surface areas of said pellet with a metal paste (31, 33);
- 10 heating the coated pellet to sinter the thermistor material and adhere the metal coat;
- removing a portion of said coated disk to obtain said predetermined resistance;
- 15 preparing a first lead (61) and a second lead (63) with each lead having an end having metal the same as in said metal paste;
- positioning a said prepared lead end in contacting relationship on each coated area (31, 33) of said pellet;
- 20 applying heat and pressure to weld each said lead end to its respective contacting coated area; and
- fusing a conformal glass coating (75) to the disk and leads.

19. A method as claimed in Claim 18 wherein said powder mix comprises primarily an oxide of nickel and an oxide of manganese.

20. A method as claimed in Claim 18 wherein said metal paste is a thick film comprising finely divided silver, platinum, and palladium.

21. A method as claimed in Claim 18 wherein said leads have a silver surface.

22. A method as claimed in Claim 18 wherein said conformal glass coating comprises coating said disk and lead ends with a glass frit and heating to fuse the frit.

23. A method as claimed in Claim 18 wherein said heating the coated pellet to sinter the thermistor material and adhere the metal coating is at a temperature of approximately 800°C to approximately
5 1500°C.

24. The method of fabricating a thermistor from a disk (11) having an upper surface (13) and a lower surface (15), of densely compacted thermistor material comprising the steps of:

5 coating said upper and lower surfaces (13, 15) of said disk (11) of compacted thermistor material with a film (31, 33) containing silver;
heating said coated disk sintering the thermistor material and fusing said film to the disk;
10 thermo-compression bonding the ends of lead wires (61, 63) containing silver to said surfaces;
and
fusing a conformal glass coat (75) over
said disk (11) and said bonded ends of said lead
15 wires (61, 63).

FIG-1

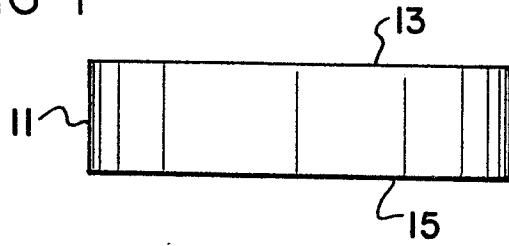


FIG-2

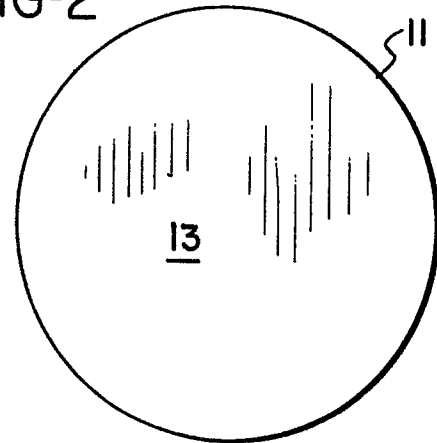


FIG-3

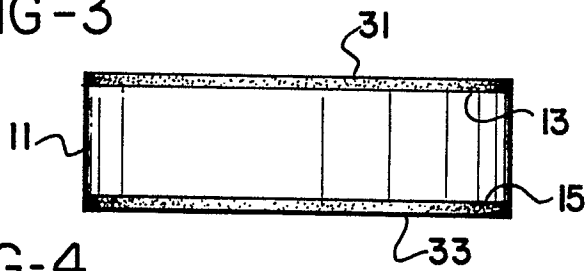


FIG-4

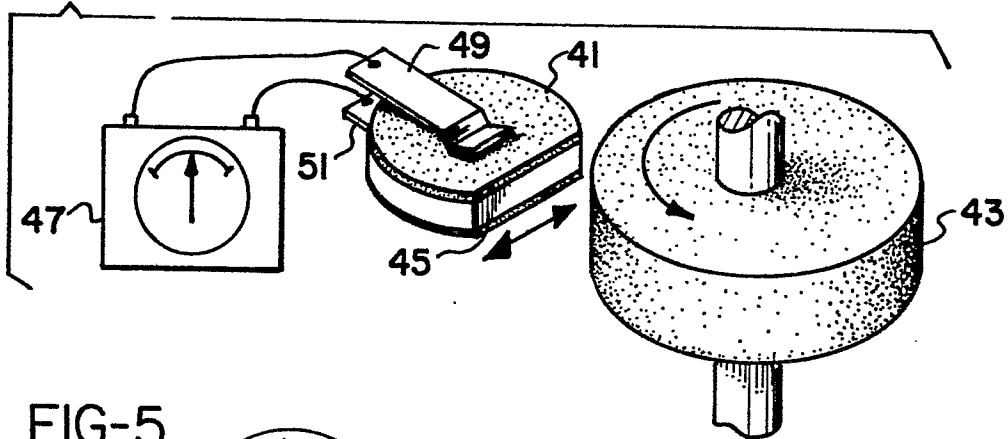


FIG-5

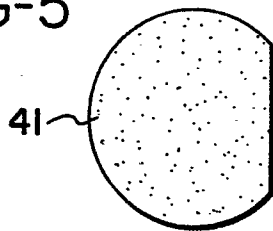


FIG-6

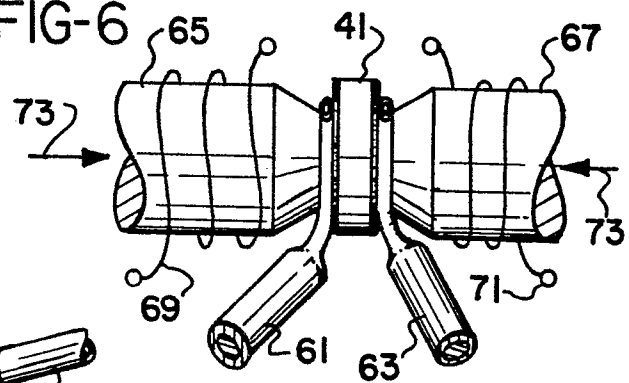


FIG-7

