Dec. 6, 1960 E. M. WORMSER ET AL 2,963,674

CONSTRUCTION FOR THERMISTOR BOLOMETERS

Filed Aug. 16, 1955

Fig. 1.

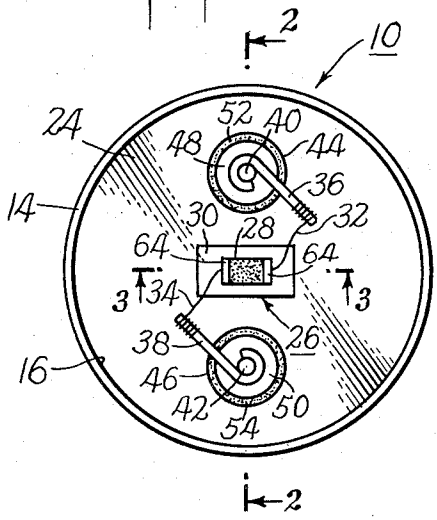


Fig. 2.

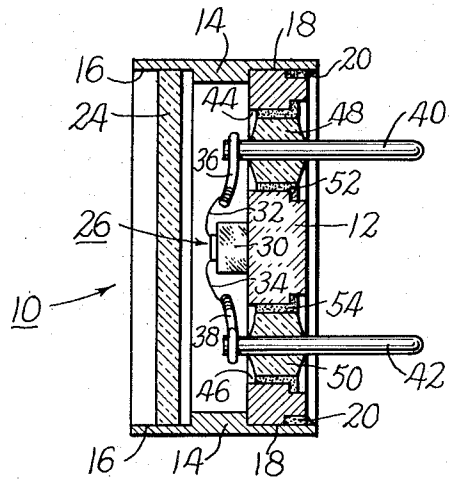
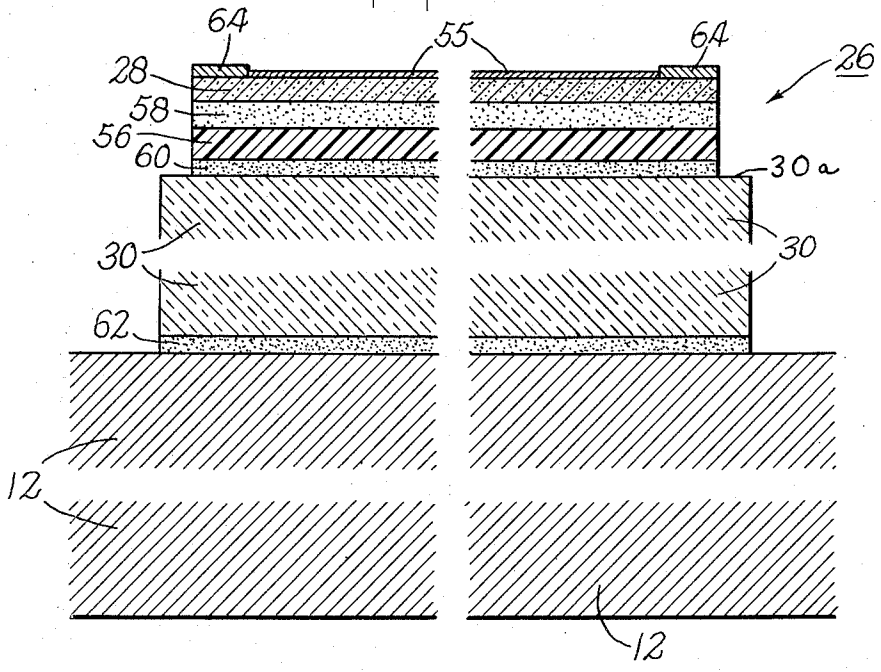


Fig. 3.



INVENTORS
Eric M. Wormser
Russell D. DeWaard
BY
John C. Blair
ATTORNEY

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CONSTRUCTION FOR THERMISTOR BOLOMETERS

Eric M. Wormser, Stamford, and Russell D. De Waard, Old Greenwich, Conn., assignors to Barnes Engineering Company, Stamford, Conn.

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This invention relates to an improved construction for radiation sensitive devices. More specifically it relates to improvements in the construction of infra-red sensitive thermistor bolometers which permit the manufacture of such devices having characteristics "tailored" for particular applications.

Thermistor bolometers are useful for measuring infra-red radiation, and thus can be used for all types of temperature measurements. In some applications they should have fast response rates to detect rapid changes in temperature or pulses of infra-red energy. In other uses it is desirable that these detectors have a very high responsivity, which is defined as the ratio of the signal developed by the bolometer to the energy falling upon it. In other applications bolometers having characteristics which represent a compromise between speed and responsivity are desired.

Prior to this invention, thermistor bolometers consisted of a thin flake of resistance material having a high negative temperature coefficient cemented to a backing block of electrically insulating heat conducting material. The flake and block assembly were mounted in a metallic housing, having a window transparent to infra-red radiation. Changes in radiation falling on the flake through the window caused it to vary in temperature, thus changing its resistance. This change was detected by applying a direct voltage to the flake and measuring the change in current flowing in this biasing circuit. Since the flake was thus electrically polarized, it was necessary to insulate it from any electrical conductor which has heretofore been accomplished by using a backing block of electrical insulating material since the adhesive layer between the flake and the block is usually too thin to provide effective insulation. The backing block also serves as a thermal conductor to carry away heat generated in the flake due to biasing current and radiation; it is thus termed a "thermal sink."

The thermal conductivity of the backing block determines in part both the rate of response and the responsivity of the thermistor bolometer. To obtain fast response rates it is desirable that the backing block conduct the heat away from the flake very rapidly, but if high responsivity is desired, the backing block should conduct heat away relatively slowly since the greater the temperature change in the flake, the greater will be its resistance change and therefore the larger will be the developed signals. Thus, to obtain a thermistor bolometer whose characteristics are tailored to a particular application the relatively fast devices of the prior art must be slowed down by measured amounts, thereby increasing their responsivity.

In the co-pending application of the applicant, Eric M. Wormser, Serial No. 459,017, filed September 29, 1954, entitled "Improved Radiation Sensitive Devices," a construction for thermistor bolometers was disclosed in which flattened flakes of thermistor material were cemented by the thinnest possible cement layers to backing blocks of materials such as beryllium oxide, magnesium oxide, sapphire and other electrical insulators which were better thermal conductors than glass or quartz, the materials previously used. The thermistor bolometers made according to this construction had much higher rates of response than those made with non-flattened flakes and the previous backing materials. This increased speed was the result of the more intimate thermal contact between the flake and the backing material, and the better thermal conductivity of the backing block. In general, as previously mentioned, if the speed of response of a device of this sort is increased, this means that the heat is conducted away from the flake more rapidly, and accordingly there is less heat to cause a change in resistance of the flake, which results in a smaller output signal. However, in thermistor bolometers made according to the above mentioned application, although speed of response was increased, the responsivity was about the same as that of glass or quartz backed bolometers. Increased thermal conduction of the backing materials made higher bias voltages possible since the steady state heat developed by the biasing current in the thermistor flake was carried away more rapidly, thus preventing flake burn-out.

In certain applications, speed is not as desirable as high responsivity. Accordingly, by deliberately reducing speed, it is possibly to increase the responsivity of a given thermistor bolometer. Heretofore, this speed reduction has been accomplished by increasing the thickness of the cement layer between the thermistor flake and the backing block. However, this method does not permit accurate control of the responsivity or the speed of response since the precise thickness of the cement is difficult to control. Further it is difficult to produce these devices in standard units on a production basis, since there are slight unavoidable variations in thickness of the cement layer among different units.

Accordingly, it is an object of this invention to provide an improved construction for thermistor bolometers which will permit accurate control of the time constant and responsivity of the thermistor bolometers and which will maintain these properties over wide temperature ranges. Another object is to provide a construction of the above character which is adaptable to production line manufacture of these devices. A further object of this invention is to provide a construction of this character which permits the development of thermistor bolometers having uniform characteristics among several simlar units. A still further object is to provide a thermistor bolometer which is simple in construction and economical of manufacture. Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the features of construction, combination of elements, and arrangement of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings in which:

Figure 1 is a top elevation of our improved thermistor bolometer taken along the line 2—2 of Figure 1, except for the lead details which are shown in elevation for greater clarity, and

Figure 2 is a vertical sectional view of our thermistor bolometer taken along the line 2—2 of Figure 1, except for the lead details which are shown in elevation for greater clarity, and

Figure 3 is an enlarged sectional diagrammatic view of the radiation sensitive portion of our thermistor bolometer and is taken roughly along the line 3—3.

of Figure 1, but certain parts shown in Figure 1 are eliminated.

Figure 4 is a graph of the frequency and decibel response.

Generally speaking, we have discovered that thin plastic films cemented between the backing block and the flake will permit tailoring of the characteristics of thermistor bolometers of the type herein described. The thermally sensitive resistor flake is cemented to the film which of course must be an electrical insulator in order not to short circuit the flake, the film being in turn cemented to the backing block, which is a material having a high thermal conductivity. Although there have been previous attempts to use coated backing blocks, such as metal blocks coated with glass or quartz, these resulted in thermistor bolometers with response rates and responsivity similar to those attainable with homogeneous backing blocks of the material. Accordingly to our understanding, two conditions caused the relatively poor performance of the previous coated backing blocks. Usually the insulating films were quite thick and non-uniform, while those contemplated in this invention are thin and of uniform thickness. The plastic films which are used herein are less than 50 microns thick some being as thin as 6 microns, and are uniform to a small percentage of their thickness. A film of 50 microns thickness is approximately two thirds as thick as the average human hair, and 6 microns is that much smaller. A second condition which caused slow response in prior devices was the use of curled or non-flat flakes of thermistor material. As described in the co-pending application of the applicant Eric M. Wormser, previously identified, the use of non-flat flakes results in cement layers between the flake and the backing block which are non-uniform in that their average thickness is much greater than the thinnest portion. These non-uniform films result in increased thermal resistance between the flake and the backing block and slower response rates. Further, because the coatings were non-uniform, the responsivity varied in manufacture and could not accurately be controlled. For these reasons coated backing blocks have not heretofore been found desirable. In thermistor bolometers made according to our invention, almost the entire thermal resistance of the backing material is concentrated between the flake and the backing block in a thin plastic layer in close proximity to the flake. Thus the heat energy not dissipated in the flake itself is dissipated almost entirely in the plastic film, which in turn heats the flake to a higher temperature than would otherwise be obtained. The total thermal resistance between the flake and the mounting is only slightly greater with the plastic coated backing blocks of this invention than with backing blocks of quartz or glass; however the concentration of this resistance close to the flake results in much higher responsivity. By varying the thickness of the plastic film, it is possible to accurately control both the response speed and the responsivity. The thicker films result in slow bolometers with high responsivity, while if thin films are used, the bolometers are faster, but have low responsivity.

Referring to the drawings in detail and particularly to Figures 1 and 2, we have here shown a construction which may be used to house and support our improved thermally sensitive device, it being understood that other structures could be utilized for this purpose. As shown herein a housing for a thermistor bolometer is generally indicated at **10**, comprising a flat base **12**, secured to a cylinder **14** to form a housing for the other parts of the device. Cylinder **14** has annular bores **16** and **18** adjacent its ends, base **12** resting in bore **18** and being held in place by a solder seal or fillet **20**. This base **12** is preferably copper, or a steel alloy which has the same coefficient of expansion as certain glasses and thus can be attached directly to them without resulting heat damage. A window **24** which is transparent to infrared energy and hence preferably made from thallium bromide iodide, a synthetic optical crystal, or silver chloride, is cemented or otherwise secured to bore **16**. Window **24**, when made of silver chloride, is coated with silver sulphide which absorbs visible and ultraviolet radiation; if the window is made of thallium bromide iodide no coating is required. The coating protects the silver chloride from actinic action. Housing **14** is preferably formed from silver or some other noble metal to inhibit reaction with the window. A radiation sensitive apparatus, generally indicated at **26**, to be more fully described hereinafter, is cemented or otherwise secured to base **12** and includes a thermally sensitive flake **28** and a backing block **30**. The ends of flake **28** are preferably gold coated and leads **32** and **34** are connected thereto and to larger leads **36** and **38** which in turn are connected to pins **40** and **42** supported in holes **44** and **46** in the base **12** by glass seals **48** and **50**. These seals are connected to the metal base by solder seals **52** and **54** and pins **40** and **42** are preferably shaped and located to plug into a standard tube socket or the like. Accordingly the device may be connected into a circuit so that a biasing voltage may be impressed across the flake **28** and signals from the flake amplified.

The structural details of the thermally sensitive apparatus **26** may be more readily comprehended from an examination of Figure 3 in which certain of the dimensions are greatly exaggerated for purposes of greater clarity. Thus flake **28** coated on its exposed surface with black lacquer **55** to enhance infra-red absorption is joined to a thin plastic film **56** by a cement layer **58**; the plastic film in turn is joined to a block **30** of material having high thermal conductivity by the cement layer **60**. This entire assembly is mounted on base **12** in any suitable manner, as by cementing backing block **30** to base **12** by a cement layer **62**. Electrodes **64** are attached to the flake to make electric connection thereto. Accordingly heat may be transmitted from flake **28** through the cement layers **58** and **60** and plastic film **56** to the backing block **30** and from there to the base **12** for further dissipation. The superior operating characteristics of our improved thermistor bolometers are not only due to the coaction of the individual parts thereof, but also to their precise physical characteristics which will now be described in greater detail.

Thus, flake **28** is a resistor commonly known as a thermistor because of its high negative temperature coefficient and ability to change resistance value when infrared rays fall thereon. Preferably mixtures of oxides of manganese, nickel, and perhaps cobalt are used in making such flakes. Such mixtures are not conveniently expressed as parts by weight since the state of oxidation of the metals is not precisely known; they are preferably expressed in the number of atoms of the particular metal present per 100 atoms of the mixture. On this basis, preferred resistance materials comprise 80 manganese to 20 nickel, or 52 manganese, 16 nickel and 32 cobalt.

It is preferable that flake **28** be "optically flat" to minimize variations in thickness of the cement layer **58**. As used herein the term "optically flat" means that the flake should pass between two plane parallel surfaces spaced apart no more than 5 microns greater than the flake thickness. For example, the standard 10 micron flake used in our thermistor construction, to be termed "optically flat," should pass between two plane parallel surfaces 15 microns apart. The flakes are preferably generally rectangular in shape; typical flakes vary from 10 to 0.05 millimeters in length and from 10 to 0.05 millimeters in width.

Returning now to Figure 3 of the drawings, cement layers **58** and **60** are of minimum thickness, i.e. as thin as possible while still performing their adhesive functions. In practice, we have found that the average thickness of layer **58** should not be greater than 10 microns

and preferably should be about 3 microns. Such layers in such range of thickness are hereinafter termed "thin." Layer **60** is even thinner, since it is formed by coating the block **30** with a thin layer of cement, placing the plastic film **56** on this layer, and rolling it under pressure to squeeze out excess cement. Thus layer **60** is between 1½ and 3 microns thick. Cement layer **58** should be thin and as uniform as the variation in flake flatness will permit. The cement should not only intimately bond together flake **28**, plastic film **56** and backing block **30**, but should also offer minimum resistance to heat flow. Cement layer **58** must be an electrical insulator to avoid short circuiting the flake, although it is not desirable to depend upon it to insulate the flake from the backing block because of its extreme thinness. Plastic resins, especially the epoxy and phenolic resins, are preferred as a general class of materials to be used for the cements, since they provide strong but flexible bonds over wide temperature ranges. The thermal conductivity of the epoxy resins is about 5×10^{-4} calories/sec.° C. cm.^{2} per centimeter of length, which is approximately the same as that of the plastic film **56**, and is $\frac{1}{2,000}$ that of the materials preferred for use in block **30** and base **12**.

The plastic film **56** which separates the flake from the backing block should be both a good electrical insulator and a thermal insulator. Thermal insulation is required so that most of the heat will be dissipated close to the flake **28** while electrical insulation is required to confine current flow entirely to the flake since extraneous currents cause noise. Further the film must be available in thin sheets, preferably less than 25 microns, in order that the low thermal conductivity of the film will not appreciably lower the speed of response of the thermally sensitive element. To prevent solvents used with the cements from changing the film thickness and perhaps perforating it, the plastic should be unaffected by organic solvents. It is desirable that the film have high temperature stability to permit use of the element over wide ambient temperatures and it is also desirable that it be available in controlled thicknesses, i.e. thin films of varied uniform thicknesses. The availability of polyester films in controlled uniform thicknesses makes possible the "tailoring" of the time constant and responsivity of the thermistor bolometer as previously explained. The material should be a thermosetting plastic so that high temperatures will not change its dimensions. We have found that polyester resin films satisfy most of these requirements and a preferred polyester is polyethylene terephthalate, a polymer formed by a condensation reaction between ethylene glycol and terephthalic acid. This material has an electrical resistivity of 10^{19} ohm-cm. at room temperatures and a thermal conductivity about one-fifth that of glass. In addition it is available in very thin sheets of uniform thickness and has excellent solvent resistance and temperature stability.

Returning to Figure 3, the backing block **30** should be a material with low thermal resistance, i.e. a good heat conductor.

We have found that beryllium oxide ceramic, magnesium oxide, and synthetic sapphire (crystalline Al_2O_3) are among the preferred materials for use as backing blocks. Of these materials, beryllium oxide ceramic has the highest thermal conductivity, being approximately 0.4 calories/sec.° C. cm.^{2} per centimeter of length, which is about ten times the conductivity of Z-cut quartz and approaches that of aluminum. The thermal conductivity of magnesium oxide is approximately ¼ that of beryllium oxide, while sapphire has a lower conductivity than magnesium oxide. A "factor of merit" has been defined for thermistor bolometers, which is directly proportional to the responsivity, and inversely proportional to the square root of the time constant. This factor of merit is substantially a constant for each type of backing material when it is plotted as a function of varying time constant, if similar flakes are used on each type of backing material and all are biased at the same fixed proportion of peak permissable bias voltage. Of the three materials mentioned beryllium oxide has the highest factor of merit, magnesium oxide the next and sapphire the lowest. However, the factors of merit of all of these materials are much higher than that of quartz or glass. Although sapphire has the lowest factor of merit of the three materials mentioned, it is desirable for certain applications since it is the easiest to handle in manufacture. Beryllium oxide is very hard to form, and care must be exercised to avoid beryllium poisoning. Machining of magnesium oxide is difficult since it is friable and breaks along cleavage planes. While the materials herein mentioned are preferable for certain applications, any material having the requisite high thermal conductivity might be used for backing blocks. It may be desirable in some applications to grind and polish the surface **30***a* of block **30** to insure that the cement layer **60** is as thin and uniform as possible.

In operation, infra-red energy falling on the window **24**, is transmitted therethrough to the flake **28**, and its temperature increases causing a change in electrical resistance. The current flowing through the flake because of the biasing voltage applied at the electrodes **64**, changes and is detected by conventional electrical circuit means. In practice it has been found desirable to use alternating rather than direct current amplifiers to amplify the flake signal. In conventional apparatus used in conjunction with that shown herein the incoming radiation is "chopped," i.e. periodically interrupted by a spoked rotating disc or the like so that the infra-red energy falling on the flake is in pulse form. Therefore, it is desirable that the flake have a reasonably fast response rate in order to follow these pulses. By using a layer **56** of polyester resin of 6 microns thickness and an optically flat flake **28** with resulting thin cement layers, we have succeeded in producing thermistor bolometers having time constants of approximately 2 milliseconds. By changing the thickness of layer **56**, this time constant can be changed by known amounts, the time constant increasing in direct proportion to the film thickness. Thus a plastic layer of 50 microns thickness will give a time constant of approximately 16 milliseconds, the responsivity increasing by a factor of about 2.8 with this slower speed.

With a thin plastic film of low thermal conductivity interposed between the flake and the backing material there is no appreciable difference in response speeds of the various materials heretofore mentioned when backing blocks and flakes of similar dimensions are used. However, the responsivity does vary depending upon the backing material. Thus the responsivity of beryllium oxide is higher than that of magnesium oxide which in turn is higher than sapphire. The increased responsivity with materials having better thermal conductivity is a result of the higher bias voltages which may be employed with the materials having higher thermal conductivity. The biasing voltage, and thus the biasing current, is determined by the rate at which the heat developed in the flake by the biasing current is carried away by the backing material. For materials of high thermal conductivity this heat developed in the flake is carried away more rapidly than with the materials of lower conductivity, and higher biasing current may be utilized which produces a larger signal for a given resistance change.

Another important advantage of this construction is the improvement in infra-red absorption obtained. Energy falling on the flake which is not absorbed by the black coating or the flake itself passes through them and is absorbed in part by cement layers **58** and **60** and by plastic film **56**. The energy not absorbed by any of these layers is reflected from the surface **30***a* of the block and is returned through the cement and plastic to the flake.

Substantially all of the incident energy is thus absorbed by the flake, or materials in close thermal relation with it.

We have described herein an improved construction for a backing block for thermistor bolometers which includes a very thin layer of electrically insulating plastic film cemented to a block of material of high thermal conductivity. A flake of thermally sensitive resistor material is cemented to the film. If the flakes are optically flat and the cement layers and thermally insulating film are thin, the resulting thermally sensitive element will have a response rate and a responsivity which are determined almost entirely by the thickness of the plastic film. Thermally sensitive elements made according to this invention thus may exhibit much greater signal output for a given amount of energy falling on them than prior constructions, and more important, the relationship between speed and responsivity may be accurately controlled.

We have suggested that polyethylene terephthalate is particularly desirable for use as film 56 but its to be understood that other plastic films, having substantially similar characteristics may also give the improved performance described; therefore our invention is not to be limited to the particular materials mentioned. Further, although we have shown only a single sensitive element in the housing of Figures 1 and 2, it is obvious that a plurality of both shielded or unshielded elements may be included in such housing.

It will thus be seen that we have provided an improved construction for thermistor bolometers, and that the objects set forth above, among those made apparent from the preceding description, are efficiently attained.

Since certain changes may be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description, and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense. It is also to be understood that the following claims are intended to cover all of the generic inventions herein described and all statements of the invention, which, as a matter of language, might be said to fall therebetween.

We claim:

1. In a device responsive to infrared radiation, the combination of a flake of optically flat thermistor material, said material being composed of a mixture of manganese oxide and nickel oxide, a non-metallic backing block of material having a high thermal conductivity adapted to serve as a thermal sink and having a substantially flat surface, a film of polyester resin secured to said substantially flat surface of said backing block, and a thin electrically insulating layer of soluble plastic resin bonding said flake to said polyester film.

2. In a device responsive to infrared radiation, the combination of an optically flat flake of thermistor material adapted to be electrically excited, a non-metallic backing block of material having a high thermal conductivity adapted to serve as a thermal sink, a film of polyester resin of low thermal conductivity and of not more than 50 microns thickness, a first thin adhesive layer joining said polyester film to said backing block, and a second thin adhesive layer bonding said flake to said polyester film.

3. In a device responsive to infrared radiation, the combination of an optically flat flake of thermistor material, a non-metallic backing block adapted to serve as a thermal sink, a film of polyester resin not more than 50 microns thick, an adhesive layer of not more than 5 microns thickness bonding said polyester film to said backing block, and a cement layer of not more than 10 microns thickness bonding said flake to said polyester resin film.

4. In a device responsive to infrared radiation, the combination of an optically flat flake of thermally sensitive metallic oxide resistance material, a non-metallic backing block having a ground and polished surface adapted to serve as a thermal sink, a film of polyester resin having high electrical insulation resistance and low thermal conductivity, a first adhesive layer attaching said film to said ground and polished surface of said backing block, and a second thin adhesive layer bonding said flake to said film.

5. In a device responsive to infrared radiation, the combination of an optically flat thermistor element, a non-metallic backing block of material having high thermal conductivity adapted to serve as a thermal sink and having a substantially flat surface, a film of polyethylene terephthalate, a cement layer joining such film to said substantially flat surface of said backing block, and means for securing said thermistor element to said polyethylene terephthalate layer.

6. The combination defined in claim 5 in which said non-metallic backing block is formed of material selected from the group consisting of beryllium oxide, magnesium oxide, and sapphire.

7. In a device responsive to infrared radiation, the combination of an optically flat thermistor element adapted to be electrically exicted, a non-metallic backing block of material having high thermal conductivity adapted to serve as a thermal sink, an organic plastic film of low thermal conductivity, an adhesive layer bonding said film to a surface of said backing block, and means securing said thermistor element to the outer surface of said plastic film.

8. In a device responsive to infrared radiation, the combination of an optically flat thermistor element, a non-metallic backing block of material having high thermal conductivity adapted to serve as a thermal sink, a homogeneous film of polymeric material having low thermal conductivity, an adhesive layer bonding said film to a surface of said block, and a second thin adhesive layer joining said thermistor element to said polymeric film.

9. The combination defined in claim 8 in which said non-metallic backing block is formed of material selected from the group consisting of beryllium oxide, magnesium oxide, and sapphire.

10. In a device responsive to infrared radiation, the combination of a flake of optically flat thermistor material, a non-metallic backing block of material having high thermal conductivity adapted to serve as a thermal sink, a homogeneous film of organic plastic of low thermal conductivity, an adhesive layer bonding said film to at least one surface of said backing block, and a second thin cement layer bonding said flake to said plastic film.

11. In a device responsive to infrared radiation, the combination of an optically flat flake of thermally sensitive resistance material, a non-metallic backing block of high thermal conductivity adapted to serve as a thermal sink, an electrically insulating polyester resin film of not more than 50 microns thickness having low thermal conductivity, an adhesive layer bonding said film to a surface of said backing block, and a second thin adhesive layer bonding said flake to said plastic layer.

12. In a device responsive to infrared radiation, the combination of a thermally sensitive resistor element having an optically flat surface, a backing block of electrically insulating thermally conducting material adapted to serve as a thermal sink and having a corresponding substantially flat surface, a substantially flat film of polymeric material of low thermal and electrical conductivity and substantially uniform thickness, an adhesive layer bonding said film to said corresponding surface of said backing block, and a second thin adhesive layer joining said surface of said thermally sensitive element to said film of polymeric material, said backing block being formed substantially of a material selected from the group consisting of beryllium oxide, magnesium oxide, and sapphire.

13. In a device responsive to infrared rediation, the combination of an optically flat flake of thermally sensitive resistance material, a non-metallic backing block adapted to serve as a thermal sink and having a corresponding substantially flat surface, a film of polyethylene terephthalate of not more than 50 microns thickness, said film being secured to said surface of said backing block by a cement layer of not more than 5 microns thickness, and an adhesive layer of not more than 10 microns thickness bonding said flake to said film, said backing block being formed of a material selected from the group consisting of beryllium oxide, magnesium oxide, and sapphire.

14. In a device responsive to infrared radiation, the combination of a thermally sensitive resistor element, a non-metallic backing block adapted to serve as a thermal sink, a homogeneous film of plastic material of substantially uniform thickness, a cement layer securing said film to a bonding surface of said backing block, and a second cement layer joining a bonding surface of said resistor element to said plastic film, said bonding surfaces being substantially identically shaped, whereby said cement layers may have substantially uniform thickness.

15. In a device responsive to infrared radiation, the combination of an optically flat flake of thermistor material composed of a mixture of manganese oxide, nickel oxide, and cobalt oxide, a non-metallic backing block of material having a high thermal conductivity adapted to act as a thermal sink and having a substantially flat surface, a film of polyester resin secured to said surface of said backing block, and a thin electrically insulating layer of soluble plastic resin bonding said flake to said film.

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