March 17, 1942. G. L. PEARSON 2,276,864

RESISTANCE DEVICE

Filed Dec. 30, 1939 2 Sheets-Sheet 1

FIG. 1

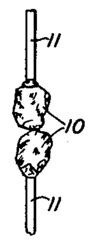


FIG. 2

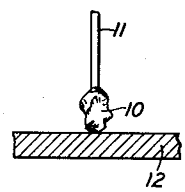


FIG. 3

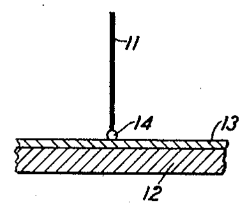


FIG. 4

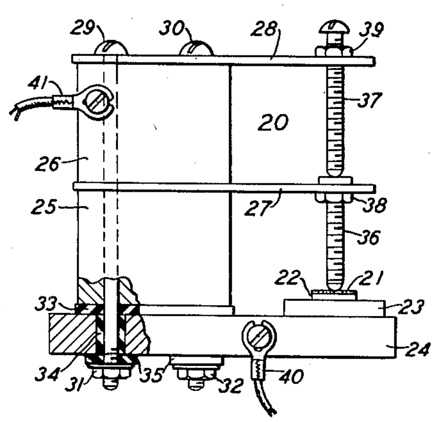
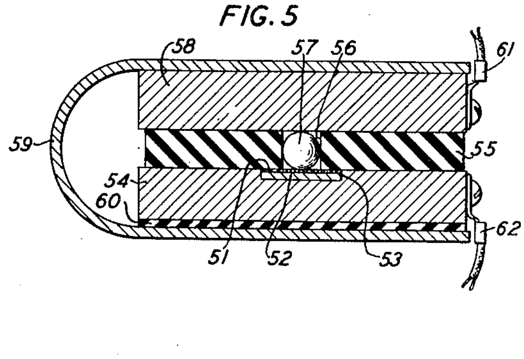


FIG. 5



INVENTOR
G.L. PEARSON
BY *Walter C. Kiesel*
ATTORNEY

March 17, 1942. G. L. PEARSON 2,276,864

RESISTANCE DEVICE

Filed Dec. 30, 1939 2 Sheets-Sheet 2

FIG. 6

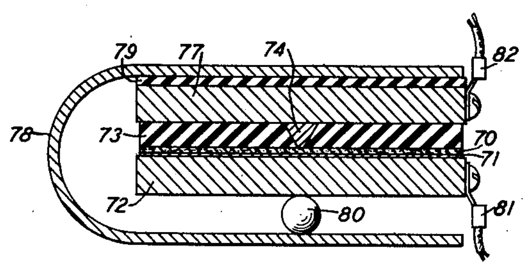


FIG. 7

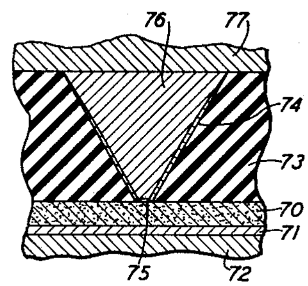
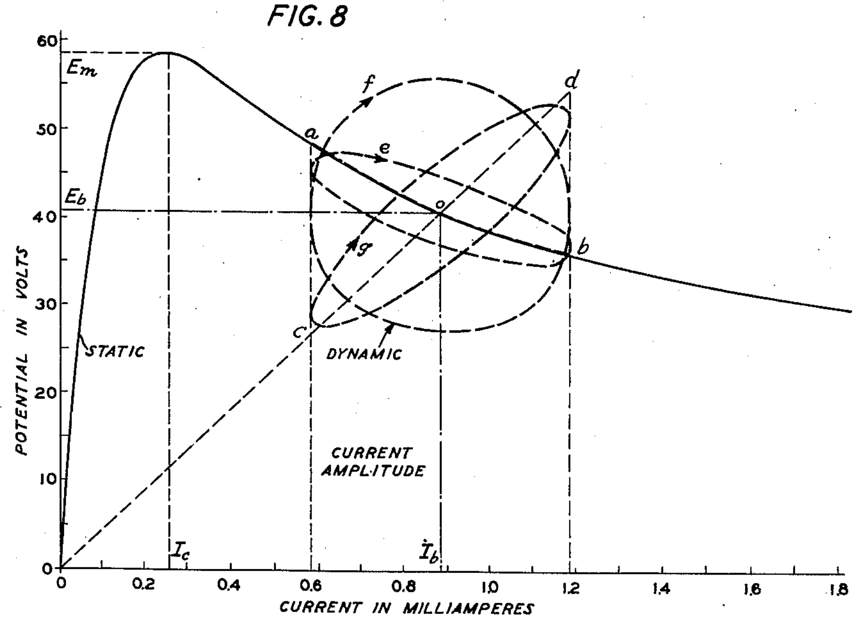


FIG. 8



INVENTOR
G. L. PEARSON
BY
Walter C. Kiesel
ATTORNEY

Patented Mar. 17, 1942

2,276,864

UNITED STATES PATENT OFFICE

2,276,864

RESISTANCE DEVICE

Gerald L. Pearson, Towaco, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application December 30, 1939, Serial No. 311,736

9 Claims. (Cl. 201—63)

This invention relates to resistors and more particularly to temperature sensitive resistors having low thermal inertia.

All materials that are ordinarily designated as conductive or resistive materials are more or less sensitive to changes in temperature. The terms "temperature sensitive," "thermally sensitive" and like expressions are, however, usually applied only to those materials that exhibit a large change in resistance for a small change in temperature. Such materials have been, for convenience, called "thermistor" materials and devices made therefrom designated as "thermistors." Those materials having conductivities lying between conductive values normally associated with conductors and with insulators, and generally designated as semiconductive materials, have been found usually to be thermally sensitive or "thermistor" materials. The semiconductive materials at present comprise a good source of material for making "thermistors."

Many of the semiconductive materials that have been investigated up to the present have a high negative temperature coefficient of resistance. For this reason, it is convenient to discuss "thermistor" action, from this viewpoint. However, positive resistance temperature coefficient "thermistors" may also be employed in a similar manner to the negative coefficient devices.

Heretofore "thermistors" have in general been rather sluggish in operation due to thermal lag. For example, in the case of a "thermistor" employing a negative resistance temperature coefficient material, when voltage is applied, an appreciable time elapses before the unit heats up and its resistance decreases. Likewise, there is a time delay after the voltage is removed, before the unit cools and again attains a high resistance. For some purposes this time delay is useful and for others it is of no particular consequence. However, a thermally sensitive resistor that could heat and cool with sufficient rapidity to closely follow applied voltage variations at audio or higher frequencies would find many useful applications.

One object of this invention, therefore, is a high speed thermally sensitive resistor or "thermistor" capable of closely following audio or high frequency variations of applied voltage.

A further object of this invention is a high "thermistor" suitable for use as an oscillator, modulator, amplifier and the like.

One feature of this invention resides in a "thermistor" unit characterized by low heat capacity and good heat transfer characteristics with relation to the surrounding medium.

A further feature of this invention lies in a "thermistor" unit having an active resistance portion of very small volume.

Another feature of this invention resides in a high speed "thermistor" having a negative resistance characteristic.

A further feature of the invention is found in "thermistors" made in accordance therewith, that exhibit a circuit characteristic which is the equivalent of reactance and which may be called effective reactance.

In accordance with another feature of this invention, a high speed "thermistor" comprises two bodies capable of electrical conduction and in mutual contact over an area that is very small with respect to the superficial area of said bodies, at least one of the bodies being of a material having a high temperature coefficient of resistance, for example, a semiconductor.

Other and further objects and features of this invention will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings in which:

Figs. 1, 2 and 3 are diagrammatic views of illustrative forms of the invention;

Fig. 4 is a view in elevation of one form of device illustrative of the invention;

Fig. 5 is a sectional view of another device illustrative of this invention;

Fig. 6 is a sectional view of still another device illustrative of the invention;

Fig. 7 is a fragmentary section of part of Fig. 6 to better illustrate details thereof; and

Fig. 8 is a plot to show the electrical characteristics of a high speed "thermistor" made in accordance with this invention.

As previously indicated the "thermistor" devices made in accordance with this invention comprise two conducting bodies, at least one of which has a high temperature coefficient of resistance and is generally a semiconductor, the bodies being in mutual contact over a very small area. Contact areas of the order of 2×10^{-7} to 1×10^{-8} square centimeters have been found satisfactory. As will be pointed out more fully in the following description of specific embodiments of the invention, the foregoing values are only indicative of the order of magnitude of the contact area and are not intended as limiting values.

The use of a small contact area is one way of confining the effective resistance of the device to a small volume. The very small volume of resistance material can be rapidly heated when voltage is applied or increased. Since rapid cooling is also necessary upon a reduction or removal of the applied voltage, the heat transfer from the body must be good. This may be accomplished in one way by having a good heat conducting material in intimate contact with the small volume of resistance material. Illustrations of this may be found in the detailed description of the embodiments of this invention.

According to Figs. 1, 2 and 3 there are shown several diagrammatic forms of high speed varistors. The device of Fig. 1 comprises two semiconductive bodies 10, such as boron crystals in single contact. Conductive members 11 are attached to the bodies 10 forming circuit connections. Another form illustrated in Fig. 2 comprises a semiconductive body 10, which may be a boron crystal, in contact with a metallic plate 12. A conductive means 11 forms one circuit connecting element and another connection may be made to the plate 12. In the embodiment of the invention shown in Fig. 3, a conductor 11, such as a wire of platinum, bears on the surface of a thin layer 13 of semiconductive material secured to the surface of a metallic plate 12. The contacting surface of conductor 11 should be shaped to minimize any tendency to deform the surface of the semiconductive layer 13 and still provide contact over a very small area. One way of doing this is to make the contacting surface of said conductor generally convex or spherical. For example, where conductor 11 is a metal wire, a bead 14 may be formed at its end or the end may be bent back upon itself to present a convexly curved contacting surface.

"Thermistors" made in accordance with this invention have a non-linear static voltage current characteristic. If a negative resistance temperature coefficient "thermistor" of this type is subjected to a direct current of increasing magnitude, the voltage drop across it is found to increase to a maximum and then decrease. In other words, the device has a declining voltage-current characteristic. The static voltage-current curve of a typical "thermistor" is shown in Fig. 8.

Dynamically, the alternating current resistance is negative in the region beyond the voltage maximum E_m for sufficiently low frequencies. Fig. 8 also indicates the dynamic characteristics. If a direct current of value I_b greater than I_c (that current corresponding to E_m) to be applied to the "thermistor," a superposed alternating current of frequency approaching zero will trace out a curve *aob* approximating the static characteristic. If the superposed current has a very high frequency, the thermal lag of the "thermistor" will prevent any change in temperature, and hence in resistance, from taking place. The voltage current trace therefore will be along the ohmic resistance line *cod*. At intermediate frequencies the superimposed current will produce traces as shown at *e*, *f* and *g* in the order of increasing frequency. At low frequencies the effective alternating current resistance is negative, at high frequencies it is positive and at intermediate frequencies it may be either positive or negative; thus for some critical frequency it becomes equal to zero. This latter is the maximum frequency at which oscillation can occur. If the resistance temperature coefficient of the thermistor is positive a current voltage curve similar to the voltage current curve of Fig. 8 may be employed to show its characteristics. This curve will have a current peak similar to the voltage peak of Fig. 8.

As has been previously indicated and as will be evident by reference to the structures disclosed as illustrative embodiments of the invention, the volume of semiconductive material carrying most of the current is very small. This is due in part to the small area of one of the contacts thereto and also in devices of the type shown in Fig. 3 to the thinness of the semiconductive layer. The small volume subjected to the heating effect of the current rapidly attains a high temperature. When the applied current is reduced, rapid cooling occurs because of the good heat conduction of the mass of metal in contact with the semiconductive material. The low thermal inertia of the device renders it capable of varying its resistance with sufficient rapidity to substantially follow the high speed current variations present when voltage at audio or higher frequencies is applied thereto. Although the thermal inertia is sufficiently low to allow the high speed action previously described, it is not negligible and is responsible for another unique characteristic of the high speed "thermistor," namely, effective reactance. The thermal lag, which is frequency dependent, affects the electrical circuit through thermal control of its resistance in a manner equivalent to the effect of inductance or capacitance thereon. In the case of a negative resistance temperature coefficient device the effective reactance is inductive in character and with a positive coefficient unit it is capacitive.

As indicated in connection with the foregoing discussion of Fig. 8, oscillation, amplification and other like phenomena can occur in the region of negative resistance, provided the frequency is not higher than the critical frequency. A high speed "thermistor" of the negative resistance temperature coefficient type may be represented by an equivalent electrical network containing a resistance in parallel with a series combination of negative resistance and inductance. In such a network the resistance represents the positive ohmic resistance and the inductance the effective inductance due to the thermal lag. At any given frequency below the critical frequency (that frequency at which the effective resistance is zero, namely, positive and negative resistance equal); the effective network of such a high speed "thermistor" comprises an effective negative resistance and an effective inductance in series. Similar networks comprising resistance and capacitance may be employed to represent the positive resistance temperature coefficient "thermistor." Several practical embodiments of high speed "thermistor" devices of the type shown diagrammatically in Fig. 3 are illustrated in Figs. 4, 5, 6 and 7.

In Fig. 4 there is shown a device comprising a thin layer 21 of semiconductive material secured to a metallic backing 22, which is attached to a metal block or plate 23 secured to the base plate 24 of a holder generally designated by the reference character 20.

The holder 20 comprises the base plate 24 of metal such as brass and a pair of blocks 25 and 26 serving as support means for spring members 27 and 28. The blocks 25 and 26 may be secured to the base plate 24 and springs 27 and 28 to the blocks by fastening means such as bolts 29 and 30 and nuts 31 and 32. The lower block 25 may be insulated from the base plate 24 by means such as insulating sheet 33. Insulating bushings 34 and washers 35 may be employed to insulate the bolts 29 and 30 and nuts 31 and 32 from the base plate.

The springs 27 and 28 which may be of the cantilever type have portions secured respectively between blocks 25 and 26 and on top of block 26. The projecting ends of the springs 27 and 28 are in alignment and respectively support contacting member 36 and adjusting member 37. The member 36, which may be of steel and in the form of a screw secured to the spring 27 by means of a nut 38, bears on the surface of semiconducting layer 21. The adjusting member 37 may also be a screw threaded into a tapped hole in spring 28 and secured in adjusted position by a lock nut 39. The point of member 37 may bear on the head of member 38.

Circuit connections may be made to semiconducting layer 21 and contact member 36 by any convenient means. The terminal members 40 and 41 secured respectively to base plate 24 and block 26 are suitable. Other means than the insulating sheet 33, bushings 34 and washers 35 may be employed to avoid a short-circuiting shunt around the contact between member 36 and semiconductive layer 21. For example, the conducting block 23 may be insulated from base plate 24 and circuit connections made from said block and at some convenient point on the holder 20.

The point of contact member 36, which is convexly curved or spherical, is applied to the surface of semiconductive layer 21 with sufficient pressure to insure mechanical stability. The pressure is adjusted so that the resistance is not affected by mechanical vibrations. When the "thermistor" is to be employed as an oscillator, further adjustment is made, if necessary, until the device oscillates in an appropriate circuit. If the thickness of semiconductive layer 21 is of the order of 1 mil or 2.5×10^{-4} centimeters, which has been found satisfactory, the contact area giving the desired result will probably be in the neighborhood of 2×10^{-7} square centimeters. In devices of this type the pressure applied by screw 37, when proper adjustment is attained, has been found to be as high as two pounds. It will thus be seen that the pressure over the small contact area is very high. With some of the materials, which have given good results, such high contact pressures cause some deformation of the semiconductive surface. Other things being equal, materials giving the least deformation at the contact are to be preferred.

In view of the high contact pressure employed the semiconductive layer must be hard and strong to resist appreciable deformation and consequent increase of the contact area.

One suitable semiconductive element comprises a thin layer of uranium oxide, about 1 mil thick, on a platinum foil backing. A suitable method of preparing such an element is as follows: Finely ground uranium oxide and floated silicon dioxide are mixed in the approximate proportion of 85 per cent and 15 per cent by weight respectively, water is added to form a thin paste which is applied to thin sand blasted platinum foil so that the oxide does not exceed a thickness of 1 mil. After thorough air drying the coated foil is passed through a furnace regulated to $1420\pm10°$ C. at a steady rate and in a total time of about three minutes to sinter the active surface.

The optimum rate of travel through the furnace is about 0.25 foot per minute. At slower rates the silica forms large crystals while at faster rates the rapid quench produces cracking and chipping of the surface and peeling of the oxide layer.

The completed foil-oxide assembly may then be cut into strips of suitable size, for example, ¼ inch by ⅛ inch (.635 by .3175 centimeter), which are individually subjected to a pressure of about 600,000 pounds per square inch in a press, to remove surface irregularities. These strips are then secured as by spot welding to blocks of metal such as brass and the assembly subjected to about 300,000 pounds per square inch pressure. The resulting assemblies are then placed in a suitable holder. See, for example, assembly 21, 22, 23 in holder 20 of Fig. 4.

Other semiconductive materials may also be employed for making the thin film on a metal backing. Some of these are: A heat treated mixture of nickel and manganese oxides such as disclosed in application Serial No. 274,114 by Richard O. Grisdale, filed May 17, 1939 now Patent 2,258,646, issued October 14, 1941; a heat treated mixture of oxides of nickel, manganese and cobalt as disclosed in application Serial No. 280,692, by Ernest F. Dearborn, filed June 23, 1939 now Patent 2,274,592, issued February 24, 1942, or boron deposited from the vapor stage on a metal such as tungsten. Thin films may also be applied to a metal backing by subjecting superposed layers of metallic and semiconductive powders to high pressure as disclosed in application Serial No. 274,101, by Earle E. Schumacher, filed May 17, 1939 now Patent 2,267,954, issued December 30, 1941.

A further embodiment of the invention of the type shown in Fig. 3 is disclosed in Fig. 5. A thin layer of semiconductive material 51 is applied to a metallic backing 52 in one of the ways heretofore described. This unit is placed in a recess 53 in a metal block 54 The recess should be of such depth that the semiconductor surface and the face of the block 54 are coplanar. A thin sheet of insulation 55 such as mica or other insulating material that may be slightly compressed by application of reasonable force thereto, is placed over the block 54. The sheet 55 is provided with a small orifice 56 of about the same diameter as its thickness. The orifice 56 is located to come over the semiconductive layer 51. A metal bead or sphere 57 of a diameter to fit orifice 56 snugly is placed therein. Another block of metal 58, similar to block 54 but having no recess, is placed over the insulating sheet 55 and metal bead 57. Clamping means, such as U-shaped member 59 of spring metal, hold the assembly together. The clamping means, if of conductive material, may be insulated from one of the blocks 54 or 58 (in the device illustrated, 54) by means of insulating material 60. The clamping means is adjusted to exert sufficient pressure to slightly compress the insulation 55 and press the bead 57 firmly against the semiconductive layer 51. The contact area and the pressure should be comparable to those employed in the device illustrated in Fig. 4. Circuit connections may be made by any suitable means such as terminals 61 and 62 attached to metal blocks 58 and 54, respectively.

In Fig. 6 is shown a form of high speed "thermistor" similar in some respects to that shown in Fig. 5. A thin layer of semiconductive material 70 may be provided with a platinum or other suitable metal backing 71. The backing 71 may be secured to a block of metal 72. On the face of the semiconductive layer 70 is a sheet or body of insulating material 73 The insulating sheet 73 may be provided with an orifice 74 That part of the orifice 74 adjacent the semiconductor 70 should have an area comparable to the contact area of the previously described devices. The remainder of the orifice may be made larger to facilitate the application of a metal contact to the semiconductor through the small opening. With the body of insulation 73 in place, a small amount of evaporated metal is condensed on the semiconductor through the orifice 74 to form a contact 75. This may be backed up with sprayed metal 76 in sufficient amount to fill the orifice.

The enlarged fragmentary view of Fig. 7 shows the details of the contact and backing Another metal block 77, similar to block 72, may be placed over insulating sheet 73 and in contact with the sprayed metal backing 76. A clamp, such as the U-shaped spring member 78, may be employed to hold the stack together. If the clamp 78 is of conducting material it should be insulated from at least one of the metal blocks 72 and 77. In the device as illustrated, block 77 is insulated by means of insulating material 79. A ball bearing 80 or similar means may be placed between clamp 78 and block 72 to aid in equalizing the pressure on the stack. Circuit connections may be made in any convenient manner as by means of terminals 81 and 82 attached respectively to metal blocks 72 and 77. In the modification of the device just described, the contact area is fixed by the size of the small end of the orifice 74 and the applied pressure is therefore not critical. Such a device would also be free from contact variations due to mechanical shock or vibrations.

Resistor units have been constructed in accordance with this invention, that will follow applied voltage variations at frequencies as high as about 17 kilocycles per second. Several units of this type connected in suitable circuits have oscillated continually over a period of several months, except for short intervals of testing and checking.

Although specific embodiments of this invention have been shown and described, it will be understood that various modifications may be made therein without departing from the spirit and scope of this invention defined in the appended claims.

What is claimed is:

1. A temperature-sensitive resistor having low thermal inertia and a declining voltage-current characteristic, comprising a sheet of metal, a thin, relatively dense film of high resistance-temperature coefficient semiconductive material on said metal sheet and presenting a plane exterior surface, a conductive body having a convex portion making contact with said film over a small area, and means for varying the contact pressure between said body and film to thereby adjust the area of contact.

2. A temperature-sensitive resistor having low thermal inertia and comprising a sheet of platinum, a thin, relatively dense film of uranium oxide on said platinum sheet and presenting a plane exterior surface, a conductive body having a convex portion making contact with said film over an area of about 10^{-8} square centimeters, and means for adjusting the contact area by adjusting the pressure of said body on the film.

3. A temperature sensitive resistor having low thermal inertia comprising a sheet of conductive material, a thin film of semiconductive material on said sheet, a body of conductive material supporting said filmed sheet, a sheet of insulating material overlaying said film with an orifice therein adjacent the film for the reception of a conductive member to position said member on said film, a second body of conductive material on the insulating sheet and making contact with said member, and clamping means for holding the assembly together.

4. A temperature sensitive resistor having low thermal inertia comprising a sheet of platinum, a thin film of uranium oxide on said platinum, a body of conductive material having a recess in one face for the reception of said uranium oxide-filmed platinum sheet, whereby the uranium oxide surface and said surface of the conductive body are coplanar, a sheet of insulating material overlaying said face and film with an orifice therein adjacent the film for the reception of a conductive member, to position said member on said film, a second body of conducting material on the insulating sheet and making contact with said member, and resilient clamping means for holding the assembly together.

5. A quick-acting thermally sensitive variable resistor comprising a conductive body having a thin hard film of high resistance-temperature coefficient semiconductive material on a surface thereof, said film having a plane exterior surface, a second conductive body having a convex portion in contact with said film, and means for adjusting the area of said contact by varying the pressure between said bodies.

6. A thermally sensitive variable resistor comprising a sheet of platinum, a firm film of uranium oxide in the order of one mil thickness on said sheet, a conducting body in firm contact with said film over an area, in the order of one millionth or less of the area thereof, and means for making electrical connection respectively to said sheet and said body.

7. A rapidly variable, thermally sensitive resistor comprising a metal body filmed with a dense high resistance-temperature coefficient semiconductive material, said material presenting a plane surface to a metal member having a convex portion thereof in contact with the material, and a mass of material having high thermal conductivity, in intimate thermally conducting relation to said semi-conductive material.

8. A resistor comprising a body of material having high thermal and electrical conductivities, a thin film of high resistance-temperature coefficient semiconductive material on said body, said film having a plane surface, a support for said body, a member of electrically conductive material having a convex portion, and means including two parallel resilient elements cooperating with the support and member to maintain the convex portion of said member in firm contact with the surface of said film.

9. A resistor device comprising a base plate of conductive material, a sheet of metallic material mounted on said base plate, a thin film of high resistance-temperature coefficient semiconductive material attached to said sheet and presenting a plane exterior surface, electrically conductive support means secured to said base plate and insulated therefrom, an electrically conductive member having a convex portion, spring means secured to said support means and maintaining the convex portion of said member in firm contact with the surface of said film, adjustable means cooperating with the spring means for varying the area of contact between said member and film by adjusting the contact pressure, and means for making electrical connections respectively to said support and base plate.

GERALD L. PEARSON.