

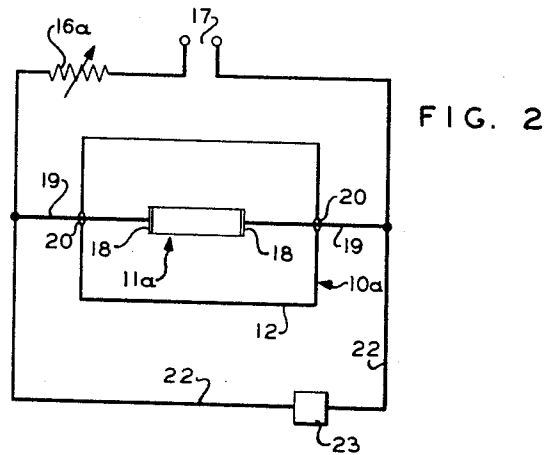
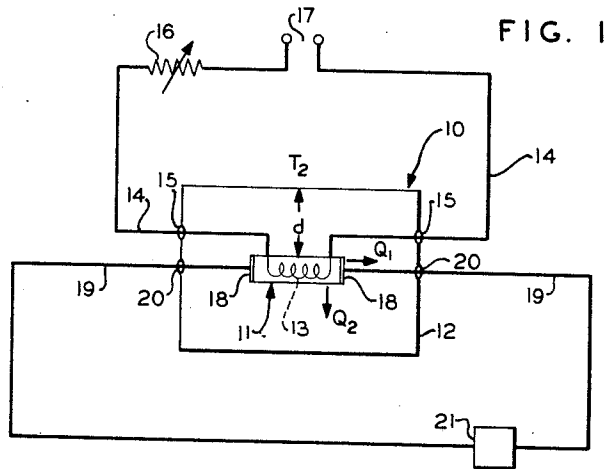
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POSITIVE TEMPERATURE COEFFICIENT SEMICONDUCTOR DEVICE

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POSITIVE TEMPERATURE COEFFICIENT
SEMICONDUCTOR DEVICE

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1 Claim. (Cl. 219—20)

This invention relates to semiconductor devices which are arranged to have a positive temperature co-efficient of resistance.

Semiconductive materials have a negative temperature co-efficient of resistance which is many times greater than the positive temperature co-efficient of resistance characterizing the so-called conductive materials. The high temperature co-efficient of resistance of the semiconductive materials makes them very valuable for temperature control purposes. However, there are many applications where resistance devices having a positive temperature co-efficient greater than that of the usual conductive materials is needed.

An object of my invention is to provide a resistance device wherein a semiconductive is used in a novel manner to provide the device with a positive temperature co-efficient.

Another object is to provide a novel resistance device which has a positive temperature co-efficient of resistance greater than that of known electrically conductive materials.

These and other objects and features of my invention will be apparent from the following description and the appendant claim.

In the description of my invention reference is had to the accompanying drawings, of which:

Figure 1 is a diagrammatic showing of an illustrative embodiment of the present resistance device; and

Figure 2 is another diagrammatic showing of an alternative form of the present resistance device.

My invention may utilize any of the semiconductive materials which have a negative temperature co-efficient of resistance. The semiconductive materials—which are those in the class between insulators and conductors—are characterized particularly by the sharpness of their negative temperature co-efficient of resistance. For instance, a semiconductor of cobalt oxide has a resistance which decreases at a rate of the order of 50% for each 27 degrees F. increase in temperature. Other typical semiconductors usable in connection with my invention comprise the p and n types including the oxides of chromium, nickel, manganese, copper, zinc, iron and so forth.

The resistance of a semiconductor can be expressed in mathematical terms approximately by the relationship

$$R = R_0 e^{-\frac{F}{T}} \quad (1)$$

where F is a constant depending on the particular material used and R_0 is the resistivity of the material at zero temperature absolute, and R is the resistivity at the temperature T.

The resistance device 10 of my invention comprises a body 11 of a semiconductive material typically in a cylindrical form. This body 11 is mounted in a sealed container 12 in spaced relation to the walls thereof, preferably at the center of the container. The semiconductor body 11 is heated electrically preferably by a heater winding 13 wrapped tightly on the body and coated by a binder such as of shellac or embedded in

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the body so as to be in close thermal relation therewith. The wire of the heater winding is, however, coated with a suitable insulative material such as Formvar to insulate the heater wire from the semiconductive material. This heater winding is connected to wires 14 which lead out of the container through respective hermetic seals 15. Connected to these wires through a rheostat 16 is a source 17 of electric current shown only as a pair of terminals to be connected to any suitable source of power. The semiconductor body 11 has end terminals 18 connected to respective wires 19 which lead out of the container through respective hermetic seals 20. The wires 19 are to be connected to any suitable apparatus 21, diagrammatically shown, which the resistance device 10 is to control. The container 12 is provided therein with a vapor or gas—herein referred to generically as a gaseous medium—which has such pressure for the temperature range in which the device is to be operated that the mean free length of path of the gas molecules is about equal to or substantially greater than the minimum distance between the semiconductor body and the walls of the container. Under this condition the heat loss by conduction from the semiconductor body 11 to the walls of the container 12 varies sharply with the outside temperature T_2 to cause a corresponding sharp variation in the temperature T_1 of the semiconductor body for any given wattage into the heater winding 13. This sharp variation is due to the well known principle that the heat conduction between two spaced members in a gaseous ambient varies sharply with the gas pressure at pressures where the mean free length of path of the gas molecules is at least of the order of the distance of spacing between the two members.

Heat is supplied to the semiconductor body 11 at a substantially constant rate of Q_0 per unit time. This is accomplished, for example, by holding the heater current substantially constant and using a material for the heater winding having a low temperature co-efficient of resistance. The rate at which the heat Q_0 is supplied to the semiconductor body is adjusted so that the temperature T_1 of the semiconductor body will be raised substantially above the temperature T_2 of the outside ambient. Under these conditions there is a heat loss Q_1 from the semiconductor body to the outside through the wires 14 and 19, and another heat loss Q_2 by conduction through the gaseous medium in the container 12. The first heat loss Q_1 is kept small by making the wires 14 and 19 small in cross section and of a material having low heat conductivity. The second heat loss Q_2 —which is the quantity on which the operation of my invention particularly depends—is proportional to the product of two factors: the temperature differential ($T_1 - T_2$) between the semiconductor body 11 and the case 12, and the heat conductivity k of the gaseous medium in the container. With increasing outside temperature T_2 the differential naturally becomes less, but such increasing outside temperature has the opposite effect of increasing the heat conductivity k of the gaseous medium. Moreover, in the pressure range wherein the mean free length of path of the gaseous molecules is greater than the spacing d , the rate of increase in the heat conductivity is sharply greater than the rate of decrease in the temperature differential. Thus, notwithstanding that the temperature differential is decreasing with outside temperature, the product of the conductivity and the temperature differential is an increasing one. This means that the heat loss Q_2 from the semiconductor body is increasing as the ambient temperature T_2 rises, and vice-versa. The increasing heat loss causes the temperature T_1 of the semiconductor body 11 to fall and

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therefor the resistance of the semiconductor body 11 to increase because of the negative temperature coefficient of the semiconductor body itself. The increasing resistance of the semiconductor body responsive to a rising ambient temperature T_2 means that the semiconductor device 10 has a positive temperature coefficient.

Although the rate of response of the present device will vary depending upon whether a gas or vapor phase is provided in the container, the character of the response remains the same. For instance, the pressure-temperature relationship of a gas is quite simple, being

$$P = P_0 T \quad (2)$$

and the pressure-temperature relationship of a vapor is relatively complicated being

$$P = P_0 e^{-\frac{D}{T}} \quad (3)$$

where D is a constant. To an approximation, the resistance response of the present semiconductor device 10 may be expressed as

$$R = C_1 R_0 e^{-\frac{H}{T_1}} \quad (4)$$

where C_1 is a constant and H may be written

$$H = \frac{F Q_0}{B} \quad (5)$$

where F is the exponential factor in the expression of the resistance of the semiconductor itself as expressed in Equation 1 and B is a quantity dependent upon the product of the gas density, average velocity of the gas molecules, specific heat of the gas at constant volume, and surface area of the semiconductor body. Also to an approximation the resistance response of the present semiconductor device 10 when a vapor phase is used may be expressed

$$R = C_2 R_0 e^{-C_3 \frac{D}{T_1}} \quad (6)$$

where C_2 and C_3 are constants and D is the exponential factor in the pressure-temperature relationship for vapor as expressed in Equation 3. By properly adjusting these variables a wide variation in the positive temperature coefficient of the semiconductor device 10 can be obtained.

In an alternative arrangement of the present device shown in Figure 2 the semiconductor body is heated by passing heating current through the body itself. Thus the body will have only the end terminals 18 with the lead wires leading therefrom through hermetic seals 20.

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The heater current is supplied to the semiconductor body, herein referred to as 11a, through the wires 19 and terminals 18 as from the same source 17 connected to the wires 19 through a resistance or other impedance device 16a. Also connected to the wires 19 are the lead wires 22 connected to an apparatus 23 to be controlled. As before, the heating current is controlled so as to supply heat at a substantially even rate to the semiconductor body 11a notwithstanding its changing resistance. The heating circuit may be effectively isolated from the circuit 22 to be controlled by using a suitable high value of resistance or impedance 16a.

I have herein particularly shown and described my invention in terms of certain preferred embodiments, but it will be understood that these embodiments are intended to be illustrative and not limitative of my invention since the same are subject to changes and modifications without departure from the scope of my invention, which I endeavor to express according to the following claim.

I claim:

In combination, a hermetically sealed container, a body of a semiconductive material having a negative temperature coefficient of resistance mounted in said container in spaced relation to the walls thereof, a gaseous medium in said container of a pressure where at the mean free length of path of the gas molecules is at least of the order of the minimum distance of spacing of said semiconductor body from said container, and means for supplying heat to said body at a substantially constant rate sufficient to raise the temperature of the body substantially above that of the outside ambient and cause said body to have a positive temperature coefficient of resistance relative to variations in said outside ambient temperature, wherein said body has end terminals, including lead wires connected to said terminals and leading through the walls of said container in sealed relation thereto, a circuit to be controlled connected across said semiconductor body through said lead wires, a source of current connected to said lead wires for heating said body to a temperature substantially above that of the outside ambient, an impedance means in the heating circuit for isolating electrically said current source from said control circuit.

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