

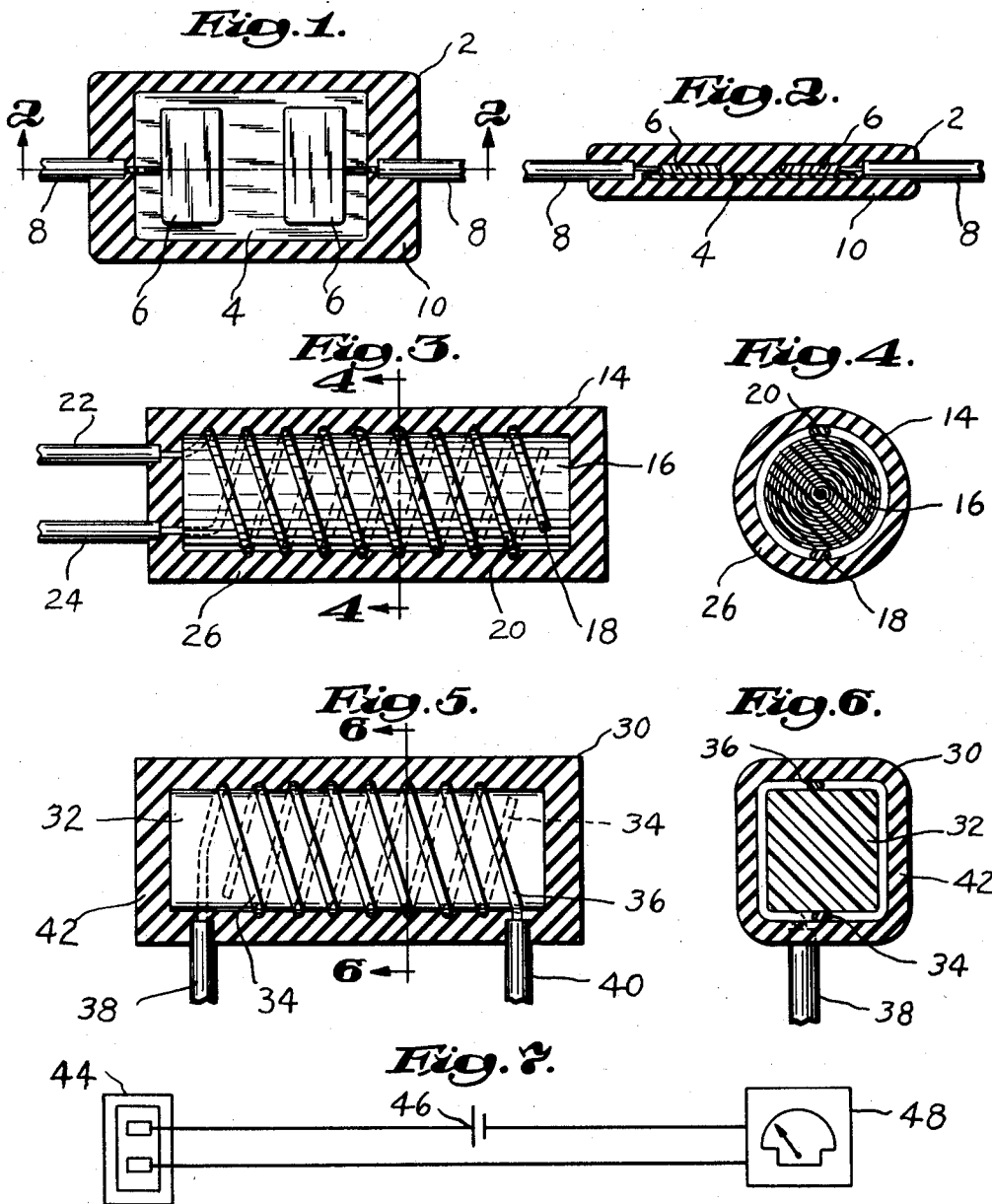
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W. A. CURBY

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TRANSDUCER TEMPERATURE-SENSING UNIT

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Inventor:
William A. Curby,
by **Dick, Champion, Bronstein & Morse**
Attorneys

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TRANSDUCER TEMPERATURE-SENSING UNIT
William A. Curby, 1663 Commonwealth Ave.,
Newton, Mass.
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This invention relates to transducers, and more particularly to methods and means for determining temperatures involving the utilization of inter-related phenomena.

This invention is based on the discovery that certain materials comprising a vapor permeable polymeric base containing a vaporizable, ionizable compound, when maintained in a closed atmosphere of predetermined character, exhibit definite and reproducible electrical semi-conductivity between laterally disposed electrodes which varies in direct proportion to the temperature to which they are exposed. Phrasing the above in terms of electrical resistance, of which conductance is the reciprocal, the resistance exhibited decreases with increasing temperature, also, of course, in definite relationship. The general relationship of temperature and resistance exhibited by embodiments of this invention, namely decrease of resistance with increase of temperature, is not affected by the pressure magnitude of the atmosphere in which the semi-conductor is disposed.

For purposes of clarity and without limitation, reference will now be made to a specific illustration. A lamina of cellophane 0.001 inch in thickness, and 11 millimeters long and 10 millimeters wide, was desiccated, and then exposed to an atmosphere at 79° F. laden with water vapor to the extent of 80% for a time sufficient to produce a condition of equilibrium. A pair of aluminum electrodes each 0.001 inch thick, and 5 millimeters by 10 millimeters in area, were disposed laterally on one surface of said cellophane and in electrical contact therewith, and in registration with said cellophane with 1 millimeter lateral space between the electrodes. The moisture-containing cellophane, which comprises a semi-conductor body, and the electrodes were encapsulated in a coating providing an electrical and hermetic seal, specifically of polyethylene terephthalate, available commercially under the trade name "Mylar" (Du Pont).

The above encapsulated unit was connected in an electric circuit with the electrodes in series with a source of direct current at constant voltage, namely a battery, and a milliammeter. With this arrangement, the resistance between the laterally-disposed electrodes was ascertained by the application of Ohm's law, namely

$$R = \frac{E}{I}$$

where E is the voltage and I is the amperage.

Upon subjecting the above-described unit at atmospheric pressure to varying temperatures, it was found that the resistance between the laterally-disposed electrodes decreased with increasing temperature in predetermined and predictable fashion. Otherwise expressed, the conductivity increased with increasing temperature.

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The actual resistance values obtained in the above calibration test are tabulated below:

Temperature (° C.):	Resistance (ohms)
0	1.4×10^7
10	1.22×10^7
20	1.06×10^7
30	9.1×10^6
40	8.8×10^6
50	7.7×10^6
60	6.8×10^6
70	5.0×10^6
80	4.3×10^6
90	3.7×10^6
100	3.1×10^6

It will be understood that the above data provides the basis for the preparation of a calibration curve, and that by thus calibrating the system with known temperatures, the readings of the milliammeter may be translated directly into measurements of temperature.

In carrying out this invention, a semi-conductor body is employed which exhibits electrical resistance between laterally disposed electrodes in the range of about 0.001 to about 200 megohms per square centimeter of electrode surface area. These electrical values, expressed in terms of conductance, would be from about

$$\frac{1}{0.001}$$

to about

$$\frac{1}{200}$$

megohms.

The semi-conductor body comprises a vapor permeable base of a polymer containing an ionizable, vaporizable compound.

The polymer base may be in the form of a roll of sheet material or in the form of an elongate, generally cylindrical body, for example of circular, square or other section. The base may also be in the form of a sheet of material.

The composition of the vapor permeable polymer base may vary, but I have found regenerated cellulose such as cellophane and unsized rayon fabric to exhibit superior properties for this purpose. Other illustrative vapor permeable base materials which may be employed in connection with this invention are other celluloses including the lower alkyl celluloses, such as ethyl cellulose and methyl cellulose, and vapor permeable vinyl resins having repeating side chain radicals of the group consisting of hydroxyl and halogen radicals, such as polyvinyl chloride. In general, cellulosic materials are preferred.

It is noted that all these polymeric base materials comprise long chain polymers having a plurality of repeating hydroxyl or halogen, particularly chloro, side chains or radicals bonded to the polymer skeleton.

A non-particulate base material is preferred in order to obtain more stable response characteristics. However, laminar material is satisfactory.

The vaporizable, ionizable compound is associated with the vapor permeable polymeric base preferably by absorption or adsorption of the compound in the form of a vapor by the base prior to encapsulation and before or after the association of electrodes therewith. Thus the base is permeated with the vapor. With a cellophane body, for

example, the cellophane is preferably first desiccated. Subsequently the cellophane is caused to carry or contain the ionizable, vaporizable compound. Preferably the ionizable compound is added to the base by exposing the desiccated base to an atmosphere of the compound in vapor form until equilibrium is established. It is not certain whether the compound is adsorbed or absorbed but in any event the base takes on the compound.

The vaporizable, ionizable compound may vary but it has been found that water, hydrogen chloride, ammonium hydroxide and ammoniacal water are highly satisfactory, water being preferred. It is noted that these compounds are ionizable into hydrogen or ammonium cations.

The compound to be used for any particular situation will vary depending on the range of intended temperature measurement, different compounds providing high sensitivity over a different range. Thus for example, subjecting the desiccated cellophane to water vapor will provide high temperature sensitivity within the range of about minus 5 to about plus 110 deg. C. Sensitivity within this same range may be achieved by subjecting the desiccated cellophane to hydrogen chloride (HCl) vapor, but the change in resistance with variation in temperature will be of a different magnitude. High sensitivity within the range of about minus 50 to 0 deg. C. is afforded by subjecting the desiccated cellophane to ammoniacal water ($\text{NH}_3 + \text{H}_2\text{O}$) or ammonium hydroxide (NH_4OH) vapor.

The functioning of the above vapors suggests their ionization to impart to the semi-conductor body electrical conductivity. It is believed that the normally non-conductive polymeric base when permeated with the ionizable compound, which may be called an activator, is rendered semi-conductive by migration of ions, hydrogen ions in the case of moisture, through the semi-conductor body. To explain more fully with reference to cellophane, cellophane is made up of a plurality of polymeric chains having a plurality of repeating hydroxyl side chain radicals weakly bonded to the polymer skeletons and some of which are closely adjacent to each other. Because of this weak bond these hydroxyl radicals form a weak chemical bond with the hydrogen ions of the water to cause ionization of the water. Probably adjacent hydroxyl radicals share a hydrogen ion so it is probably bonded to adjacent hydroxyl ions. Upon coupling a source of electrical current to the semiconductor body, the charge of electrons built up on the positive electrode surface of the body causes the weak hydroxyl-hydrogen ion bonds to be broken. The released hydrogen ions are attracted to other adjacent hydroxyl radicals with which they become weakly bonded. This bond is again broken and the hydrogen ions migrate to other adjacent hydroxyl radicals on the same polymer skeleton and adjacent skeletons and in this way hydrogen ions finally migrate to the negative electrode to cause conductance through the semi-conductor body.

It is believed that resistivity decreases as the temperature is increased because the higher the temperature the greater the molecular activity and hence the faster the rate of migration of the hydrogen ions. It is believed that one of the reasons why better results are achieved with non-particulate base materials is that with particulate base materials the non-uniform interfacial areas which affect migration of the hydrogen ions contribute to non-uniform response. In view of the above theoretical considerations it would appear that any vapor permeable polymer can be used as a base having side chain radicals which are weakly bonded to the polymer skeleton and which are also capable of forming a weak bond with the cation or anion of the ionizable compound and that any ionizable, vaporizable compound can be used as an activator having a cation or anion capable of being weakly bonded to the side chain radicals. In this way the particular ion involved is capable of migrating through the semi-conductor body as aforesaid.

It should be understood that the above is only a theoretical explanation and the invention is not intended to be limited by such explanation.

The amount of ionizable compound contained by the vapor permeable polymeric base is not critical so long as there is a substantial amount. The greater the amount of ionizable compound contained in the polymeric base the less the resistance. Consequently, as the amount of ionizable compound is decreased the resistance increases to a point at which, as in all semi-conductors, it ceases to be practicable for use with presently known circuitry. Also as the amount of ionizable compound is increased the resistance decreases to a point at which, as in all semi-conductors, sensitivity is diminished too greatly. By way of example with moisture as an activator and cellulose as a base it has been found that resistance ranges achieved by exposing the desiccated cellulose to atmospheres having relative humidities between about 40% and 100% at 80° F. until equilibrium is established, are satisfactory.

The thickness of the semi-conductor body is not critical. A pair of electrodes of substantial area is associated with the semi-conductor body in such fashion as to be sensitive to temperature changes but relatively insensitive to changes in pressure. This is achieved by spacing them laterally on the same side of the polymer body, as distinguished from being oppositely disposed with relation to each other, in such a way that forces normally expected to be applied to the body will be presented to both electrodes in substantially the same directions and by substantially the same amounts, whether that body be in the form of sheet material or in the form of a generally cylindrical rod. In the case of a cylindrical body, the electrodes advantageously may take the form of spaced wires spirally wound around the periphery of the body.

The materials of which the electrodes are composed are such that they will not affect the immediate environment and surface characteristics will not be affected by the environment within the encapsulating unit. It has been found that platinum is a highly advantageous electrode material. Other metals and alloys have been found suitable as electrode material, for example, gold, silver, aluminum, nickel silver and Phosphor bronze.

The semi-conductor body containing the ionizable compound and with associated electrodes, is encapsulated to prevent changes of condition of the semi-conductor body and electrodes and thus to render constant the response of the unit to changes in temperature.

The encapsulating material is one which will completely seal off the atmosphere outside of the unit, which will seal the interior of the unit electrically, and which will maintain the integrity of the predetermined atmosphere and environment within the unit. Epoxy resins have been found highly suitable for use as the encapsulating or casing material and a specific example of a commercial product for this purpose is marketed under the commercial name of "Scotchcast No. 5." Other materials may be employed for encapsulating purposes, for example, glass, lead solder and other soldering alloys and other vapor proof resins such as vinyl resins. Silicone grease also exhibits possibilities for this purpose. When metal or other electrically conductive substance is employed as the encapsulating material, the encapsulation will be suitably electrically insulated from the semi-conductor body, electrodes and leads.

In the drawings:

FIG. 1 is a longitudinal section of a transducer temperature-sensing unit embodying this invention;

FIG. 2 is a transverse section taken on line 2—2 of FIG. 1;

FIG. 3 is a longitudinal section of a transducer temperature-sensing unit with wire-form electrodes spirally wound on a semi-conductor body constituted of rolled sheet material;

FIG. 4 is a vertical section taken on line 4—4 of FIG. 3;

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FIG. 5 is a longitudinal section of another form of transducer temperature-sensing unit wherein the wire-form electrodes are spirally wound in opposite directions on a cylindrical core or body of substantially rectangular cross-section;

FIG. 6 is a sectional view taken on line 6—6 of FIG. 6; and

FIG. 7 is a diagrammatic view of a simple form of circuit embodying a temperature transducer of this invention and current measuring means.

In the drawings illustrating specific embodiments of the invention there is shown in FIGS. 1 and 2 a transducer temperature-sensing unit 2 embodying a semi-conductor body 4 comprising a sheet of non-particulate vapor permeable polymeric material which conveniently may be cellophane, which is 0.001 inch thick, 11 millimeters long and 10 millimeters wide and which has been desiccated and then exposed to an atmosphere at 79° F. having a relative humidity of 80% for a period of 36 hours to produce a condition of equilibrium, whereby a substantial amount of water vapor is absorbed or adsorbed by the cellophane. Electrodes 6 are shown as spaced apart laterally on the same side or surface of the body 4 and in electrical contact with the body. Electrodes 6 may be composed of aluminum sheet material. Leads 8 are electrically connected to the electrodes 6. Vapor-proof capsular coating 10 encloses the semi-conductor body, electrodes and leads and constitutes an electrical and hermetic seal for the unit 2. Capsular coating 10 may be composed of epoxy resin.

In the transducer temperature-sensing unit 14 illustrated in FIGS. 3 and 4 the semi-conductor body 16 is shown as composed of a cylindrical roll of cellulosic sheet material such as cellophane which has been desiccated and exposed to an atmosphere having a humidity of 80% just as the cellophane sheet in the FIG. 1 embodiment. Laterally spaced aluminum electrodes 18 and 20 are helically disposed on the surface of cylindrical body 16 and in electrical contact therewith. Leads 22 and 24 constitute a continuation of electrodes 18 and 20. Capsular coating 26 of epoxy resin constitutes an electrical and hermetic seal for the parts enclosed therewithin.

In FIGS. 5 and 6 the transducer temperature-sensing unit 30 is shown as having a semi-conductor body 32 of solid cylindrical shape and of generally rectangular cross-section. It is molded ethyl cellulose and contains water vapor added in the same manner as the sheet of FIG. 1. Aluminum wire-form electrodes 34 and 36 are shown as wound helically in opposite directions on the body 32, said electrodes being electrically connected to leads 38 and 40. Capsular coating 42 of epoxy resin forms an electrical and hermetic seal for the enclosed parts.

In FIGS. 1 to 6 inclusive, the water vapor carried by each semi-conductor body is not shown.

In FIG. 7 is shown a simple circuit wherein a transducer temperature-sensing unit 44 of this invention, shown diagrammatically, is connected to a battery 46, providing an electrical source of constant voltage, and a milliammeter 48. When transducer 44 was subjected to temperatures to be determined, the resistance across the electrodes of the transducer varied in inverse relation to the temperature. Said resistance was determined by Ohm's law from the reading of the milliammeter 48 and the known voltage supplied by battery 46. The temperature was also determined directly from milliammeter readings from previously prepared calibration data as outlined hereinabove.

A temperature sensing unit exactly like FIG. 1 was made except that sheets of vapor permeable polyvinyl chloride were used in place of the cellophane. The resistance of this unit when connected in the circuit of FIG. 7 also varied inversely with the temperature and changes in temperature were measured by measuring the current through the unit at constant voltage.

Another temperature sensing unit exactly like FIG. 1 was made except that the cellophane sheets were exposed

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to an atmosphere of 80% hydrogen chloride (HCl). This unit satisfactorily measured temperature change.

Another unit was made like FIG. 1 except that the cellophane sheets were exposed to an atmosphere of 80% ammonium hydroxide (NH₄OH) and it satisfactorily measured temperature change.

It will be understood, of course, that where a source of constant current is employed, the resistance between electrodes may be determined by Ohm's law by means of measurements of voltage at temperatures to be determined.

It will be seen that the present invention provides for the quick and reliable determination of temperatures by simple means, easily operated and which may be of very small size, e.g. the size of a pin head. The advantages of such a temperature sensing device in situations where there is required miniaturization and measurement of extremely short lived temperature changes too short in duration to heat the relatively large masses conventionally used in heat sensing device will be appreciated.

The transducer of the present invention may be made flexible by the use of a flexible semi-conductive body 4 in FIG. 1 (the cellophane sheet is flexible), flexible electrodes 6 in FIG. 1 (these electrodes are thin and hence flexible) and a flexible encapsulating material 2, e.g. rubber or an epoxy resin or a vinyl resin.

It will be understood that various changes and modifications may be made in the subject matter herein disclosed, while still coming within the scope of the invention.

I claim:

1. A transducer temperature-sensing unit comprising, in combination, a semi-conductor body comprising a solid, base material of the group consisting of a cellulosic material and polyvinyl chloride, said base material containing a predetermined quantity of an ionizable, vaporizable compound selected from the group consisting of water, hydrogen chloride, ammonium hydroxide, and ammoniacal water, a pair of electrodes spaced apart laterally and in electrical contact with said semi-conductor body, and a capsular coating enclosing said semi-conductor body and electrodes and constituting an electric and hermetic seal.

2. A unit according to claim 1, said cellulosic material comprising at least one of the group consisting of cellophane, ethyl cellulose, methyl cellulose and unsized rayon fabric.

3. A transducer temperature-sensing unit comprising, in combination, a semi-conductor body exhibiting electrical resistance between laterally disposed electrodes in the range of about 0.001 to about 200 megohms per square centimeter of electrode surface area, said semi-conductor body containing a predetermined quantity of an ionizable, vaporizable compound of the group consisting of water, hydrogen chloride, ammoniacal water and ammonium hydroxide, a pair of electrodes spaced apart laterally and in electrical contact with said semi-conductor body, and a capsular coating enclosing said semi-conductor body and electrodes and constituting an electric and hermetic seal.

4. A transducer temperature-sensing unit comprising, in combination, a semi-conductor body comprising a solid vapor permeable polymeric base material of the group consisting of cellophane, ethyl cellulose, methyl cellulose, unsized rayon fabric and a vapor permeable vinyl resin containing a predetermined amount of an ionizable, vaporizable compound of the group consisting of water, hydrogen chloride, ammoniacal water and ammonium hydroxide, a pair of electrodes spaced apart laterally and in electrical contact with said semi-conductor body and a capsular coating enclosing said semi-conductor body and electrodes and constituting an electric and hermetic seal.

5. A transducer temperature-sensing unit comprising, in combination, a semi-conductor body comprising at least one lamina of vapor permeable cellulosic sheet material containing a predetermined quantity of an ionizable, vaporizable compound selected from the group consisting of water, ammonium hydroxide, and ammoniacal

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water, a pair of electrodes spaced apart laterally on the same side of said semi-conductor body and in electrical contact therewith, and a capsular coating enclosing said semi-conductor body and electrodes and constituting an electrical and hermetic seal.

6. A transducer temperature-sensing element comprising, in combination, a semi-conductor body of cylindrical shape and comprising a cellulosic material containing a predetermined quantity of an ionizable, vaporizable compound selected from the group consisting of water, ammonia hydroxide, and ammoniacal water, a pair of spaced electrodes helically disposed on the surface of said cylindrical semi-conductor body and in electrical contact therewith, and a capsular coating enclosing said semi-conductor body and electrodes and constituting an electrical and hermetic seal.

7. A transducer temperature-sensing unit comprising, in combination, a semi-conductor body comprising a cylindrical roll of cellulosic sheet material containing a predetermined quantity of an ionizable, vaporizable compound selected from the group consisting of water, ammonium hydroxide, and ammoniacal water, a pair of spaced electrodes helically disposed on the surface of said cylindrical semi-conductor body and in electrical contact therewith, and a capsular coating enclosing said semi-conductor body and electrodes and constituting an electrical and hermetic seal.

8. A transducer temperature-sensing unit comprising, in combination, a semi-conductor body composed of regenerated cellulose, said semi-conductor body containing

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an amount of water vapor represented by the exposure of desiccated regenerated cellulose to an atmosphere having a relative humidity between about 40% and 100% at 80° F. until equilibrium is established, a pair of electrodes spaced apart laterally and in electrical contact with said semi-conductor body, and a capsular coating enclosing said semi-conductor body and electrodes and constituting an electrical and hermetic seal, the materials of the electrodes being such that they will not affect the immediate environment and such that their surface characteristics will not be affected by the environment within said capsular coating.

9. A temperature sensing unit comprising a semi-conductor body composed of a polymeric base material having a plurality of repeating side chain radicals selected from the group consisting of hydroxyl radicals and halogen radicals, said polymeric base material containing a vaporizable compound which is ionizable into cations of the group consisting of hydrogen cation and ammonium cation, a pair of laterally spaced electrodes in electrical contact with said semi-conductor body, and a vapor impervious coating enclosing said semi-conductor body and electrodes and constituting an electrical and hermetic seal.

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