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J. S. COURTNEY-PRATT
PIEZORESISTIVE COMPENSATORS

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FIG. 1

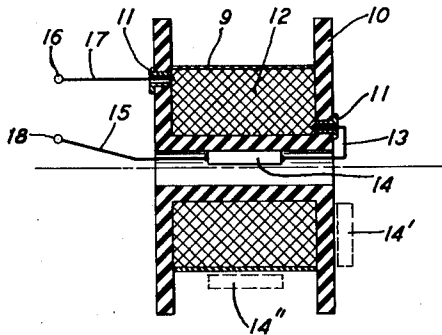


FIG. 2

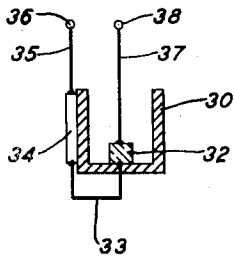


FIG. 3

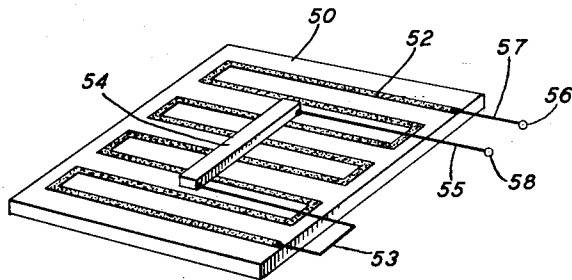
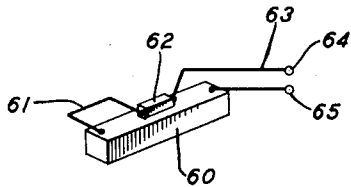


FIG. 4



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PIEZORESISTIVE COMPENSATORS

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This invention relates to arrangements for compensating for the changes in the resistance of electrical elements with changes in temperature.

In many prior art circuit arrangements, variations in the electrical resistance of resistive, inductive or other circuit elements with changes in temperature have been found to be of such magnitude as to make it imperative that either the devices be maintained within an enclosure the temperature of which is closely regulated within a predetermined narrow range or that some other equally inconvenient steps be taken to avoid or to compensate for or to otherwise neutralize the resistive changes occurring as the temperature varies.

It is, accordingly, a principal object of the present invention to eliminate difficulties of the above described nature and to simplify the compensating or neutralizing methods and apparatus by means of which resistive changes with temperature can be reduced to negligible magnitude.

It has been found that elements cut from single crystals of certain materials, known as piezoresistive materials, have very large variations of resistance when subjected to varying strain. The changes in resistance are linear with strain and free from "hysteresis" effects. They can be either positive or negative (i.e., they can either increase or decrease with increasing strain) depending upon the specific material and the orientation of the element with respect to the crystallographic axes of the single crystal from which it is cut. Throughout this application and the appended claims it is to be understood that the conventional Miller crystallographic indices are to be used in defining orientations with respect to single crystal structures.

The above-mentioned piezoresistive elements may also, as is well known to those skilled in the art, have substantial changes of resistance with temperature changes or they may have resistances which remain virtually constant with changes in temperature. Since the changes of resistance with temperature are not always linear over wide ranges of temperature, it may often be found advantageous to employ piezoresistive elements which have a virtually constant resistance over the operating temperature range anticipated. In some cases, however, it may be advantageous to employ both the changes with temperature and changes with strain to effect compensation.

The more important of the presently known piezoresistive materials are silicon, germanium, gallium arsenide, indium antimonide, silicon carbide, aluminum antimonide, aluminum arsenate, aluminum phosphide, gallium antimonide, indium arsenate, and gallium phosphide. As it is well known to those skilled in the art, these materials may be of either "n-type" or "p-type" or may be predominantly of one of these types but have layers or regions of the other type. See, for example, the book entitled "Introduction to Solid State Physics," by C. Kittel, 1953, John Wiley & Sons, Inc., New York, chapter 14, page 273, and FIG. 14.5, page 279.

In the application of the principles of the present invention it is noted that a great many electrical circuit component units, such as resistors, inductors, semiconductor diodes and the like consist of active conductive portions which may or may not be supported by or on a housing, core, form, or frame. The supporting portion

if present is commonly of insulating material or it is at least electrically insulated from the active conductive portion. The supporting portion, furthermore, usually also expands proportionately as its temperature increases. The active portions of the units more usually increase in resistance with increasing temperature, though a few, such as semiconductor diodes, may decrease in resistance with increasing temperature. For units, such as resistors and inductors, the resistances of which usually increase with increasing temperature, temperature compensation can be effected by firmly attaching a piezoresistive element to the unit or to its supporting means if it has one so that the element will be subjected to increasing strain as the temperature increases. The piezoresistive element should, of course, have a resistance which decreases with increasing strain at substantially the same rate as that at which the resistance of the unit to be compensated increases with increasing temperature. The unit and the compensating piezoresistive element can then be connected electrically in series (or in parallel) to provide a combination the net resistance of which does not vary as the temperature increases.

Obviously, for a unit the resistance of which decreases with increasing temperature, a compensating element whose resistance increases correspondingly with increasing strain and temperature should be employed.

In general a substantially different orientation with respect to the crystallographic axes of the single crystal from which it is cut will be required for piezoresistive elements the resistance of which is to increase (rather than to decrease) with increasing strain upon them, as will be described in detail hereinafter.

The above and other features, objects and advantages of the invention will be more readily perceived from a perusal of the following detailed description of specific illustrative embodiments of the principles of the invention as exemplified in the accompanying drawings, in which:

FIG. 1 illustrates a first embodiment of the invention as applied to an inductance or resistance element wound on a form or spool;

FIG. 2 illustrates a second embodiment of the invention as applied to a semiconductor diode assembly;

FIG. 3 illustrates a third embodiment of the invention as applied to a printed circuit unit; and

FIG. 4 illustrates a fourth embodiment of the invention as applied to a resistive bar.

In more detail in FIG. 1, a form, or spool, 10, which is preferably of an insulating material such as a ceramic, serves to contain a winding 12. A protective covering 9 may be applied over the winding 12 as shown. Winding 12 may be of insulated copper wire if the device is primarily intended to provide inductance, or of insulated wire of a highly resistive material, such as Nichrome, if the primary purpose is to provide resistance. In the latter case the "bifilar" type of winding, well known and widely used by those skilled in the art, is of course preferable to reduce the inductance of the winding to a negligible value.

In either case, the resistance of the winding 12 will usually increase appreciably with increasing temperature. Likewise, the whole unit including the form 10 will expand with increasing temperature. To stabilize the resistance of the unit irrespective of temperature changes, an element 14 of a piezoresistive material is firmly attached to a surface of the unit. In FIG. 1, by way of specific example, it is attached to a surface of the form 10. Element 14 is then connected electrically in series with winding 12 between terminals 16, 18, via leads 13, 15 and 17, as illustrated.

While as specifically illustrated, element 14 is attached to an inner surface of the form, any other suitable surface

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of the assembly can be selected. For example, other suitable locations are on a side of the form as illustrated by broken line element 14' or a surface of the winding as illustrated by broken line element 14". As the unit expands with increasing temperature, element 14 or its alternates 14' and 14" will be subjected to an increasing degree of strain.

The resistance of element 14 should, of course, decrease with increasing temperature by amounts equal to the corresponding increases in resistance with increasing temperature of winding 12, in order that the resistance appearing at terminals 16, 18 should be constant irrespective of temperature changes.

The piezoresistive element 14 for an assembly of the type illustrated in FIG. 1 should preferably be cut from a single crystal of the class of materials consisting of germanium (n-type), silicon (n-type) or indium antimonide (p-type). If of germanium (n-type), it should be oriented with respect to the crystallographic indices of the crystal along the [111] direction as defined by the conventional Miller crystallographic indices. If of silicon (n-type) it should be oriented along the [100] direction and if of indium antimonide (p-type), it may be oriented along either the [111] or the [100] direction.

In FIG. 2 a silicon diode rectifier element 32 is mounted in a housing 30. As is well known to those skilled in the art, the resistance of such an element decreases with increasing temperature. A piezoresistive element 34 is firmly attached to housing 30 so as to be subjected to increasing strain as housing 30 expands with increasing temperature. Element 34 is connected electrically in series with element 32 via leads 37, 33 and 35 to terminals 36 and 38, as illustrated. In order that a resistance which is constant with changing temperature should exist at terminals 36, 38, it is obvious that the resistance of piezoresistive element 34 should increase with increasing temperature by precisely the same amounts for each temperature as the resistance of element 32 decreases.

Preferably piezoresistive materials for this purpose are of the class consisting of germanium (p-type) and silicon (p-type). The piezoresistive element should be cut from a single crystal of the material with its longitudinal axis parallel to the [111] direction with respect to the crystallographic axes of the crystal.

In FIG. 3, a flat rectangular member of an insulating material such, for example, as that known by the trade name "Bakelite," has on its upper surface a "printed circuit" 52. Also firmly attached to its upper surface as, for example, by a strong adhesive having good insulating properties, is a piezoresistive element 54. A suitable adhesive is, for example, the resin known by the trade name "Araldite." Printed circuit 52 may, for example, provide a predetermined, substantially noninductive, resistance. With increasing temperature, however, member 50 will expand and the resistance of printed circuit 52 will increase.

Piezoresistive element 54 will of course be subjected to increasing strain as the temperature increases. Element 54 is connected electrically in series with printed circuit 52, via leads 53, 55 and 57 to terminals 56, 58, as illustrated. As for the arrangement illustrated in FIG. 1, in that of FIG. 3 the resistance of element 54 decreases with increasing temperature just sufficiently to offset the increase in resistance of printed circuit 52 with increasing temperature. Suitable piezoresistive materials and the orientations with respect to the crystallographic axes of the single crystal from which the element 54 is cut can be precisely as defined hereinabove for the arrangement of FIG. 1.

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Finally, in FIG. 4 a strip or bar 60 of carbon has mounted thereon and firmly attached thereto by an insulating adhesive such as "Araldite" a piezoresistive element 62. Element 62 is connected in series with bar 60 between terminals 64, 65. As the temperature increases the resistance of bar 60 increases but that of element 62 decreases by like amounts so that the resistance appearing at terminals 64, 65 remains substantially constant with temperature. Suitable piezoresistive materials and the orientations with respect to the crystallographic axes of the single crystal from which the element 62 is cut can again be as described for the arrangement of FIG. 1.

Numerous and varied other arrangements and modifications of the above-described illustrative arrangements can be readily devised by those skilled in the art which will clearly be within the spirit and scope of the principles of the present invention. No attempt has been made to exhaustively illustrate all such possible arrangements.

What is claimed is:

1. The combination which comprises a circuit unit, the resistance and the overall dimensions of the unit varying in a known manner with changes in temperature, a piezoresistive member firmly attached to the unit so that it will be subjected to a stress which is proportional to the temperature, the resistance of the member varying principally as a result of the stress to which it is subjected in a manner inversely related to the known manner of variation of the resistance of the unit, and means electrically interconnecting the unit and the piezoresistive member in series whereby the combination presents a constant resistance regardless of temperature changes.

2. The combination of claim 1 in which the piezoresistive member is a material selected from the class consisting of germanium, silicon and indium antimonide.

3. The combination of claim 2 in which the circuit unit is a printed circuit and the piezoresistive element is attached in superimposed position over the unit by a strong electrically insulating adhesive.

4. The combination of claim 1 in which the unit is a semiconductor diode rectifier.

5. The combination of claim 1 in which the piezoresistive member is a material selected from the class consisting of p-type germanium and p-type silicon.

6. In combination, a circuit unit, a solid state member, the resistance of which varies principally in inverse proportion with stress to which it is subjected, strong insulating adhesive means mechanically binding the member to the unit so that the member will be subjected to a stress which is proportional to temperature, and conductive means interconnecting the member and unit electrically.

References Cited in the file of this patent

UNITED STATES PATENTS

2,212,247	Randolph	Aug. 20, 1940
2,783,341	Wisman	Feb. 26, 1957
2,842,669	Thomas	July 8, 1958

FOREIGN PATENTS

1,400	Great Britain	Sept. 20, 1882
98,499	Switzerland	Mar. 16, 1923

OTHER REFERENCES

Smith: Physical Review, vol. 94, No. 1, pp. 42-49 (1954).

Herring: The Bell System Technical Journal, vol. 34, No. 2, pp. 237-290 (pp. 251-258 discusses piezoresistance).

Pincherle and Radcliffe: Advances in Physics, vol. 5, pp. 272-322 (1956). (Note page 278.)