June 30, 1970 F. ZANDMAN ET AL 3,517,436

PRECISION RESISTOR OF GREAT STABILITY

Original Filed May 4, 1965 2 Sheets-Sheet 1

Fig. 1.

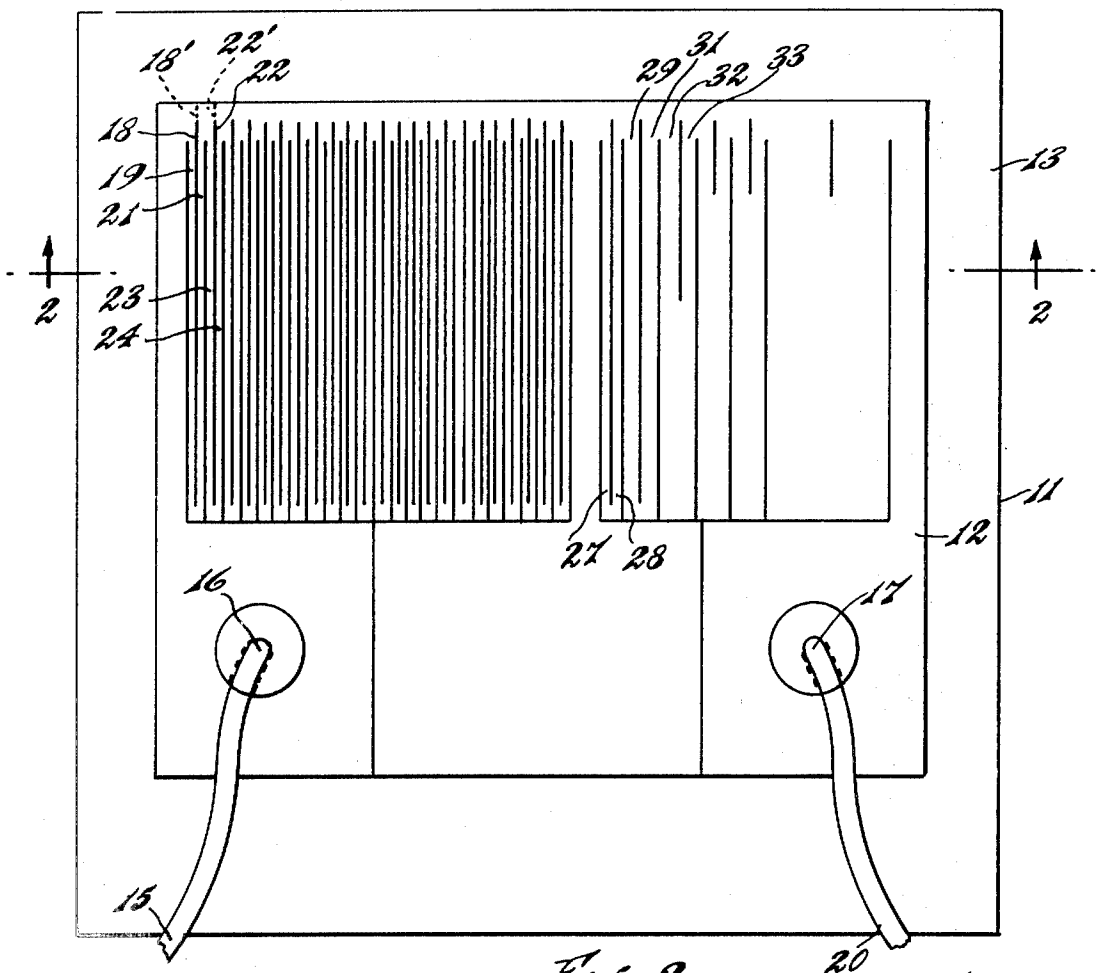


Fig. 2.

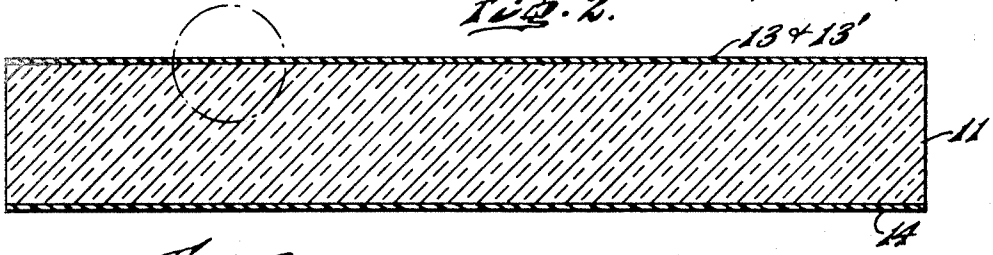


Fig. 3.

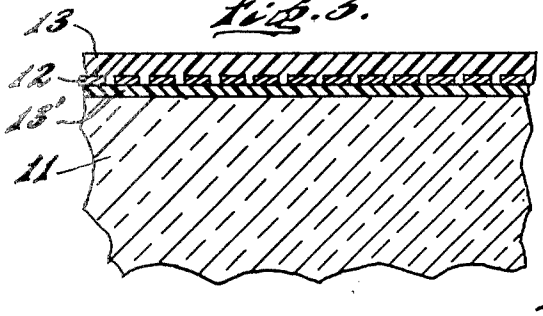
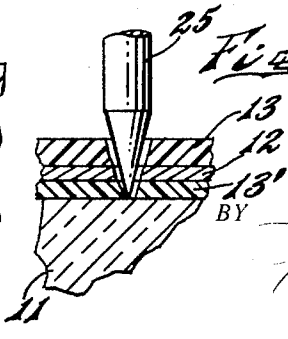


Fig. 4.



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Fig. 5.

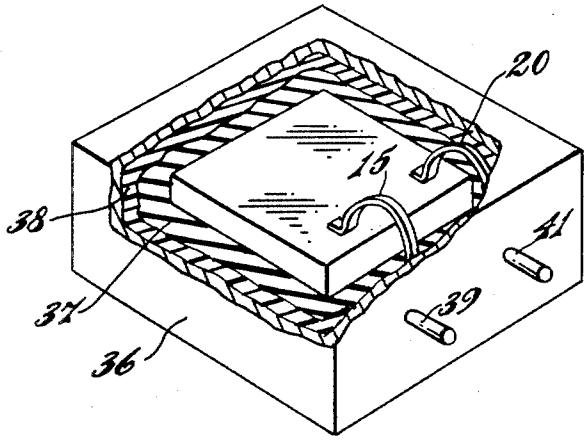
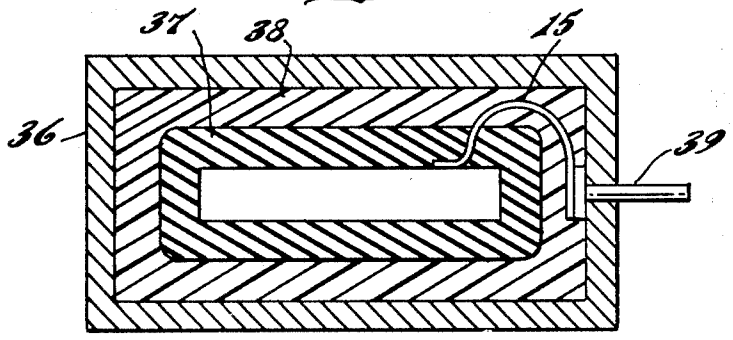


Fig. 6.



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PRECISION RESISTOR OF GREAT STABILITY

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Original application May 4, 1965, Ser. No. 453,098, now Patent No. 3,405,381, dated Oct. 8, 1968. Divided and this application Nov. 1, 1967, Ser. No. 701,794

Int. Cl. H01c *1/02, 17/00*

U.S. Cl. 29—613 3 Claims

ABSTRACT OF THE DISCLOSURE

A process of manufacturing a precision resistor having a predetermined pattern of thin metallic film supported on a substrate wherein the resistance value of the resistor is adjusted after a plastic coating has been applied to the thin metallic film.

CROSS-REFERENCED TO RELATED APPLICATION

This application is a division of Ser. No. 453,098, filed on May 4, 1965, now U.S. Letters Patent No. 3,405,381.

The present invention relates to electrical components and especially resistors. It is particularly concerned with high-precision components, such as resistors capable of very high stability and a low, closely controlled temperature coefficient of resistance.

In the past, attempts have been made to construct precision resistors by winding wire of a specially selected alloy upon a rigid form. The alloy selected was a material having a low temperature coefficient of resistivity. It was found that variations of temperature caused some dimensional variation in the form, and accordingly caused changes in the dimensions of the resistive wire element. These resulted in undesirable changes of resistance. Such units not only have disadvantages of sensitivity to ambient temperature but also are difficult and expensive to construct and to adjust to predetermined precise resistance values. Furthermore, it is very difficult to construct them in such a way as to avoid appreciable inductance. Moreover, they lack compactness. Any attempt at miniaturization greatly increases the difficulty of manufacture and hence the cost of such resistors.

One approach toward eliminating the effect of dimensional changes in the support for a precision alloy wire resistor has been the elimination of rigid support for the wire. The resistive wire was suspended loosely in a mass within an oil-filled chamber, in order that it would be free from any stresses. Such an arrangement, however, is difficult to make and presents problems with respect to sealing. Also, it involves special problems of insulating the portions of the resistive wire from each other.

It is also known to produce a resistor by photo-etching of a metal film on a substrate. However, such a resistor, especially in small sizes, introduces problems of temperature compensation and stability.

An object of the present invention is to provide a precision electrical component such as a resistor overcoming the foregoing disadvantages.

It is an object of this invention to provide a precision resistor which is reliable, economical to construct, capable of being made in extremely small sizes, substantially free of inductance, possessed of great short-term and long-term electrical and mechanical stability, and having a predetermined tightly controlled temperature coefficient of resistance.

It is a further object to provide a resistor capable of yielding extremely high stability with respect to variations of ambient temperature and moisture.

In accordance with the present invention, a high-precision resistor is constructed by supporting a thin film of a selected metal alloy upon a substrate having known physical properties, the substrate being many times thicker than the metallic film (preferably, of the order of 100 to 1,000 times thicker). The metallic film is caused to have a predetermined pattern, such that electric current flows along a conducting path of very great length and extremely small width, this pattern preferably including a great number of parallel narrow linear path portions in a planar array. The side of the substrate having thereon the resistor film of predetermined pattern is coated with an epoxy resin, and the opposite side of the substrate is similarly coated to equal thickness with epoxy resin of the same kind. These oppositely disposed coatings of epoxy resin provide symmetry with respect to their mechanical effects upon the substrate, so as to avoid any tendency to cause bending thereof. Similar balance can be obtained with unequal coatings of different characteristics. Moreover, the epoxy resin on the conductive layer reinforces the resistive path and protects it from mechanical damage, and also protects it from any skin acids which might otherwise reach it in the course of being handled.

An embodiment of a resistor in accordance with the present invention is illustrated in the accompanying drawings, wherein:

FIG. 1 is a plan view of the resistor;

FIG. 2 is a cross-sectional view of a said resistor taken on the line **2—2**;

FIG. 3 is a magnified cross-sectional view showing in greater detail the encircled portion of FIG. 2;

FIG. 4 is a magnified fragmentary view diagrammatically illustrating one way in which the path resistance may be adjusted; and

FIGS. 5 and 6 are a perspective view with part broken away and a cross-sectional view, respectively, of an encapsulated resistor embodiment of the present invention.

In a preferred embodiment, a resistor of the present invention, as illustrated in FIGS. 1, 2 and 3, comprises a substrate **11** having an etched-pattern resistor layer of bulk metal film **12** fixed to one surface thereof. Coatings **13** and **14** of a hard epoxy resin are applied to the resistor surface and the opposite surface of the substrate. The two opposite epoxy coatings are so related to each other as to result in a sandwich which does not bend or warp as a consequence of changes of temperature or moisture absorption by the coatings.

The substrate **11** may be made of glass having a temperature coefficient of expansion of the order of 3 parts per million per degree F. In an illustrative resistor unit, substrate **11** may be of the order of ¼ inch by ¼ inch with a thickness of 0.04 inch.

The bulk metal film **12** may be made from a resistive alloy such as one of the Nichrome alloys, wherein nickel and chromium are the principal metals. This film may be of the order of 0.0001 inch thick.

The metallic film **12** is photo-etched to a pattern which establishes a narrow conductive path of much greater total length than the dimensions of the face of substrate **11**. This step may be carried out after the film has been bonded to the substrate as by the layer **13'** of plastic thereunder (FIG. 3), or it may be carried out when the metallic film is on a thin support such as plastic layer **13'** but before being bonded to substrate **11**. To perform the photo-etching, the face of the thin alloy film opposite the layer **13'** is covered with a photosensitive masking medium such as Kodak Photo-Resist (KPR). By means of a photographic exposure and development, the KPR is retained in contact with the surface of the film only in the desired resistor pattern and is removed from those portions where the alloy film is to be etched away. An etch-

ing process is then used to remove the exposed portions of the thin alloy film.

One example of a suitable pattern for the film after etching is shown in FIG. 1. The junctions of the flexible leads **15** and **20** are shown at **16** and **17**. These may be welded junctions, with reinforcing epoxy mounds. As the pattern appears in FIG. 1, a very low resistance path exists between these two junctions, extending along the left side, across the top, and down the right side of film **12** as shown in said illustration. By extending the long, narrow gap **18** along the dotted line **18'** to the upper edge of the film, as by cutting with a scribing tool or with a fine abrasive cutter, the current is required to flow through narrow linear path portions **19** and **21**. Upon extending the next long, narrow gap **22** to the upper edge of the pattern as by scribing along dotted line **22'**, the current path is further lengthened to pass through narrow linear portions **23** and **24**. With this process, as many of the long, narrow portions as desired may be included in the current path between terminal areas **16** and **17**. As will be apparent, in order to include in the current path a great number of the long, narrow portions similar to portions **19, 21, 23** and **24**, a transverse cut may be extended across several of the gaps such as gaps **18** and **22** near their ends.

As illustrated in the right-hand side of FIG. 1, the pattern in which the film is exposed and etched may include several wider portions and portions of shorter lengths, so that an operator is enabled to complete the steps of bringing about the desired resistance value with the inclusion of one or more of the lower-resistance increments as may be needed. Examples of such wider and shorter portions in the film pattern for various amounts of incremental resistance are indicated at **27, 28, 29, 31, 32** and **33**.

With the alloy film etched in the desired pattern and bonded to one surface of the substrate **11** as by a suitable epoxy bonding cement **13'**, further epoxy material **13** is added, covering the surface of the metal film. This precedes the adjusting of the resistance by cutting, referred to above. FIG. 4 illustrates the protective reinforcement provided by the epoxy plastic material **13, 13'** which embeds the metallic film **12**. As the cut is being made through the outermost plastic **13** and at least part way through the alloy film **12**, either with a stylus **25** or with an abrasive cutter or other tool, the plastic holds the film **12** in position along the boundaries of the cut and resists any tendency for the film to be detached from the substrate.

The upper protective epoxy coating comprising layers **13** and **13'** may have a total thickness of 0.001 inch. There is also applied to the opposite face of the substrate **11** a further epoxy coating **14**. Epoxy coating **13, 13'** and the opposite epoxy coating **14** may be of equal thickness and identical characteristics in order that the stress contributions which they make to the flat surfaces of the glass substrate shall be balanced, and shall not tend to cause bending or warping of the glass substrate. Along with this elimination of bending, any tendency toward long-term dimensional instability due to stress relaxation is substantially overcome. Alternatively, the same result can be obtained by coatings of different material characteristics provided that their thicknesses are properly related.

The glass substrate has a temperature coefficient of expansion of the order of 3 parts per million per degree F. The epoxy or other plastic coatings **13, 13'**, and **14** on top and bottom of the glass substrate have a much higher temperature coefficient of expansion, of the order of 40 parts per million per degree F. Furthermore, said epoxy coatings tend to expand or contract as their moisture content varies. Hence, the balanced application of the epoxy or other plastic to both sides prevents it from causing bending of the device.

The modulus of elasticity of the glass substrate is many times higher than that of the epoxy material. Hence, the expansion and contraction of the unit in length and width are determined mainly by the temperature coefficient of expansion of the glass. Inasmuch as the total thickness of the epoxy layers in the described embodiment is of the order of one-twentieth the thickness of the glass substrate, and the modulus of elasticity of the epoxy is of the order of one-thirtieth of the modulus of elasticity of the glass substrate, the tendency of the epoxy to expand with temperature by a factor of ten times greater than the expansion of the glass is made comparatively small by the relative thinness of the epoxy material and its far lower modulus of elasticity.

The resistive alloy film, etched in its predetermined pattern and bonded to the glass substrate, being of the order of one hundredth to one thousandth the thickness of the glass, exerts minimal influence upon the dimensional responsiveness of the unit to the changes of temperature and moisture. The changes of resistance in the path ultimately determined in the patterned film between the junctions **16** and **17** is influenced by the following factors:

(a) The temperature coefficient of resistivity of the alloy of which the patterned metal film is comprised;

(b') The elongation and narrowing and consequent increase of resistance of the alloy film caused by the expansion of the symmetrically coated substrate with increase of temperature (and conversely, the compression and broadening of the alloy film when the symmetrically coated substrate contracts with decreasing temperature);

(b'') The variation of resistance as a function of the stress produced in the alloy film when the symmetrically coated substrate expands or contracts with changes of temperature.

As will be readily apparent, the factors b' and b'' above represent the resultant effect of the forces produced in the substrate and the forces produced in the coatings thereon.

By the selection of a nickel chromium alloy with such minor alloy components as to provide a desired curve of resistivity versus temperature and a desired temperature coefficient of expansion, the resistor may be made to have a reliable temperature coefficient of resistivity as low as 1 part per million per degree C. in the vicinity of a desired design temperature such as 25° C. and to have an extremely low overall temperature coefficient of resistivity throughout a range from −55° C. to +175° C. In general, the alloy consisting primarily of nickel and chromium will have a greater temperature coefficient of expansion than the glass substrate. Hence, with increasing temperature, as the glass substrate elongates and carries with it the alloy film layer, the alloy film is subjected to compressive stress. Conversely, as the glass substrate contracts with decreasing temperature and the alloy layer tends to undergo greater contraction, the resistive metallic film which is bonded to the glass and constrained to duplicate the contraction of the glass is subjected to tensile stress.

Provided that the net sum effect of the resistance change component due to changing stress in the alloy film and the resistance change component due to expansion or contraction of the film is substantially equal to the temperature coefficient of resistivity of the alloy under stress-free conditions, and of opposite sign, the overall temperature coefficient of resistivity of the device is substantially zero. Since the last-named factor is not linear, the device will have a predictable variation of its temperature coefficient of resistivity throughout the design temperature range.

For most applications, it is desirable to have the precision resistor encapsulated. As shown in FIGS. 5 and 6, the resistor made in accordance with the present inven-

tion may be encapsulated in a plastic or metal housing **36** wherein suitable potting material or materials are included to embed one or more resistor units such as that described above. In order to protect the resistor unit against any substantial mechanical forces exerted by or through the potting material, the resistor unit is provided with a sheath of soft rubber, polyurethane foam, or other very soft material. Such soft material **37** may be used alone, filling the space inside case **36** surrounding the coated substrate, if desired; alternatively, the soft material **37** may in turn be surrounded by a hard filler **38** such as an epoxy. The soft material **37**, with a thickness preferably many times greater than the thickness of the epoxy layers on the substrate, serves as a protective cushion by virtue of its very low modulus of elasticity.

As shown in FIGS. 5 and 6, the flexible ribbon conductors **15** and **20** from the resistor element extend to terminals **39** and **41**. By virtue of the soft cushion **37** and the flexible conductors **15** and **20**, the dimensional changes in the hardened potting material, which may be of the order of five to ten times greater than the dimensional changes which the resistor unit itself tends to undergo, are isolated and prevented from forcing the resistor unit to depart from its design characteristics.

The illustrated application of the principles of the invention to the making of a precision resistor demonstrates many important advantages. With the extremely compact construction, minimum values of inductance and distributed capacitance are achieved. A very wide range of resistance values is readily provided. A given pattern-etched metal film is conveniently adjusted precisely to any desired resistance value within a very wide range.

Substantial heating of the resistor by electric power can be tolerated without damage. Since the resistor is miniature, it is suitable for use in applications where space is at a premium. It may be included as a part of a miniaturized circuit. Other portions of the circuit may be built directly upon the substrate of the resistor. Two or more resistors may be made on a common substrate, Where desired, a second resistor or resistance path may be disposed on the face of a substrate opposite the face on which the first resistance path is established.

Where space permits and greater power dissipation capability may be desired, the elements of the resistor may be made larger. The principles of the present invention may be used in a device having a thickness of an appreciable fraction of an inch, with a substrate face area which may be as great as a square inch or greater. As will also be apparent, the substrate may be a metal body, the resistive metallic film being insulated therefrom by plastic layer **13** in contact with the substrate.

As many changes may be made and many widely different embodiments may be constructed without departing from the spirit of the present invention, the accompanying drawings and description are intended not by way of limitation but rather illustration of one form which may be taken by the invention, the scope of the invention being indicated by the claims.

What is claimed is:

1. The process of manufacturing a precision resistor of great stability comprising: bonding a metallic layer of an alloy film having appreciable resistivity to one surface of a rigid substrate having two opposed flat surfaces and which is of the order of 100 to 1,000 times the thickness of the alloy film, covering the layer of alloy film with a photosensitive masking medium, exposing said photosensitive masking medium to a photographic exposure source establishing thereon a pattern for providing a continuous metallic path many times longer than the length and width of said metallic film, developing the photosensitive medium to establish the unexposed portions thereof, subjecting the mask film to an acid bath for attacking the exposed portions of the film, coating the alloy film with a plastic coating which is thicker than the alloy film but of a lesser order of magnitude than the thickness of the substrate, and cutting through the plastic coating and the alloy film to supplement the pattern etched in said film, thereby lengthening the current flow path and increasing the total resistance presented by said alloy film after the film has been coated with the plastic coating.

2. The process defined in claim **1**, further including applying a plastic coating to the opposite face of said substrate substantially to balance the forces exerted by the first plastic coating applied to the substrate.

3. The process defined in claim **2**, further including applying a housing to surround said substrate with its alloy film and coatings, said housing being spaced from said substrate with a pliable cushion of material having a low modulus of elasticity present in the space between the housing and the coated substrate.

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U.S. Cl. X.R.

29—620