Dec. 19, 1939. W. SCHOTTKY 2,183,755

THERMONEGATIVE RESISTOR

Filed April 25, 1935

Fig. 1a

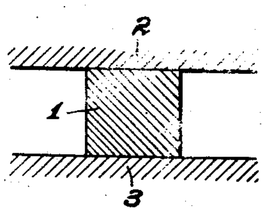


Fig. 1b

Fig. 2

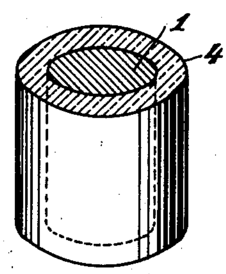


Fig. 3

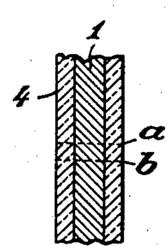


Fig. 4

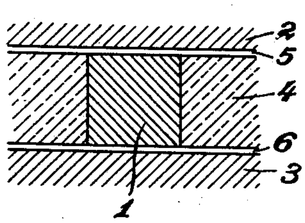
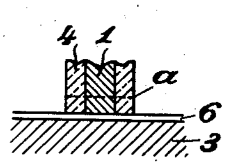


Fig. 5



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THERMONEGATIVE RESISTOR

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5 Claims. (Cl. 201—63)

My invention relates to resistors having a descending voltage-current characteristic and to a method for manufacturing the same, and more particularly to resistors having a descending voltage-current characteristic, brought about by the influence of the heat through Joule effect developed in the resistors and which are known in the art as thermonegative resistors. Such resistors are made of conductors having a negative temperature coefficient of resistance which are hereinafter designated as α-conductors in contradistinction to β-conductors which have a positive temperature coefficient.

The invention has for its main object the manufacture of thermonegative resistors having an extremely small thermal time constant as is desired for the amplification of electrical oscillations.

It is well known in the art to bring about a negative resistance effect by contact between a crystalline material and a metal wire. Further, it is well known to manufacture negative resistors by pressing powder or suitable substances, the absorption of gases being an important factor in attaining a negative resistance characteristic. Finally, arrangements are known in which the effect of the negative resistor is brought about by applying a metal point to the poor conducting surface skin (oxides and the like) of a large-sized metal electrode.

The above-mentioned negative resistors have disadvantages because the negative resistance characteristic owing to the uncertain contact making or the uncertain current paths is not stable or not always reproducible and also the manufacturing of the resistors presents difficulties.

According to the present invention a negative resistance characteristic is brought about in the case of an α-conductor of the above-described character by the fact that this conductor is made of a homogeneous material and is given such a shape that the current path is determined by the geometrical form of the conductor and that the heat through Joule effect is chiefly dissipated by heat conduction. The flow of current, consequently, takes place through the entire cross-section of the resistor and is not dependent on particular internal or external circumstances; for instance, on the form of the electrodes through which the current flowing through the resistor is supplied or carried off or upon contact effects which may accidentally be brought about between the individual parts of a composite resistor (powder resistors). By the fact that in the case of the thermonegative resistor according to the invention the heat through the Joule effect is to be carried off by conduction, this resistor is in contrast to the known α-conductors, in which the heat through Joule effect is carried off by radiation, and for which, consequently, the conditions to be fulfilled as to the construction, the dimensions and the operation as well are quite different. The method of manufacture of the thermonegative resistor according to the invention makes its operation independent of a complicated forming process which, in the case of other negative resistors, for instance, of powder resistors, is in some cases necessary in order to bring about the descending resistance characteristic.

The resistor according to the invention must above all have a relatively small thermal time constant in order that the descending characteristic may also exist with respect to instantaneous variations of current. For this reason the dimensions and the dissipation of heat of the α-conductor are chosen in such a manner that in the case of a small variation of current the equilibrium temperature to be attained adjusts itself within fractions of a second in the zone of the descending characteristic.

According to the invention the α-conductor is arranged between two metal electrodes or is provided with two electrodes which possess with respect to the cross-section of the α-conductor relatively large dimensions and, besides, a good heat conductivity. It is preferable to manufacture these electrodes wholly or partly of silver.

A practical embodiment according to the invention may be a form in which a wire- or ribbon-like α-conductor is embedded in a solid refractory insulating material the heat being dissipated from parallel surfaces, which lie in the direction of the current, as well as from the lateral surfaces of the α-conductor, i. e., transversely to the direction of current. Particularly in the case of suitable dimensioning and a suitable insulating material such as, for instance, crystallized material the α-conductor may be cooled transversely to the direction of current in a relatively intensive manner, whereby the thermal time constant is in addition reduced. Such a reduction of the time constant is necessary in view of the amplification of electrical frequencies as above described.

Further details of the invention will be apparent from the following description taken in connection with the drawing, wherein the embodiments of the invention are shown on greatly exaggerated scale, the natural size of the resistors being about 1 mm. or less.

Fig. 1*a* is a diagrammatic section through an α-conductor between two metal electrodes;

Fig. 1*b* shows a conductor element of irregular cross section;

Fig. 2 is a perspective view of a conductor having the form of a cylinder;

Fig. 3 is a section through a conductor in a stage of manufacture;

Fig. 4 is a view similar to that of Fig. 1*a*, showing a modification thereof; and

Fig. 5 is a view similar to that of Fig. 3, showing a modification of the manufacturing process.

Fig. 1*a* illustrates an arrangement in principle in which 1 denotes a piece of an α-conductor; for instance, of a metallic oxide, arranged between two metal electrodes 2 and 3 which serve to supply or to carry off the current. The body 1 may have any cross-section whatever, for instance, as shown in Fig. 1*b*. If it has the form of a cylinder, the current then flows in the direction of the cylinder axis. The body 1 is preferably made from a wire or a ribbon by cutting off a piece thereof. For the sake of simplicity it is preferable to choose a circular cross-section for the body 1.

Another method of manufacture according to the invention consists in that a relatively large layer of α-conductor material is placed between metal plates forming the electrodes 2 and 3, and is firmly applied thereto. Subsequently, the conductor material is removed from the metal plates, with the exception of a small cylinder or disk 1, by a mechanical operation or a chemical method, for example, by etching. By this operation a resistor of very small dimensions is obtained which, in spite of its small size adheres sufficiently to the electrodes. These electrodes, which are then extending for a relatively great area perpendicularly to the direction of the current, may, for example, be of a circular shape, the diameter of which is relatively great with respect to the conductor body 1.

To promote according to the invention also the dissipation of heat perpendicularly to the direction of current it is particularly advantageous to surround the α-conductor in the radial direction with a refractory insulator as disclosed in Fig. 2 in which 4 represents the insulator. In order to carry the invention into effect it is preferable to manufacture the body 1 from a wire which is surrounded by a tube of corresponding insulating material; for instance, by a glass capillary tube and is sealed throughout its length to the tube by preventing air bubbles or hollows from being created therein. A disk is then cut off from such a body which is turned or ground to the desired dimensions. This process is shown in Fig. 3 in which 1 denotes the α-conductor, 4 the glass capillary tube and *a*, *b* are the surfaces (in dotted lines) of the body obtained after the cutting or grinding process.

In order to accelerate the dissipation of heat in the desired manner dimensions are necessary which appear to be relatively small. Thus, it has proved convenient to grind the α-conductor to a length amounting to 1/20 mm. and less, whereas the diameter of this conductor amounts to 1/10 mm. or fractions thereof. It may be preferable to choose the diameter and length of the α-conductor in the same order of magnitude.

In order to render the contact of the α-conductor at the end surfaces as intimate as possible it is preferable to provide each of the opposite surfaces of the body 1, 4 with an adhesive metal layer with which further solid electrodes are brought into intimate contact, as shown, for instance, in Fig. 4. The adhesive metal layers are designated in this case by 5, 6, and the solid electrodes by 2 and 3. It is also preferable particularly if the thickness of the shaped body is less than 1 mm. to grind off first the shaped body after one of the parallel sides is firmly secured to its metal electrode. This method is shown in Fig. 5, in which 3 denotes the one solid electrode, 6 the adhesive metal layer and 1, 4 the shaped body. *a* represents the limiting surface to which the shaped body is ground after the body has been firmly secured to the adhesive metal layer 6.

The embedding of the α-conductor in the refractory insulating material may be preferably effected when the insulating material is in a soft state; for instance, as above described by sealing the α-conductor in a capillary tube. The embedding may also be effected by allowing the insulating material in a molten state to crystallize around the solid α-conductor; for instance, by immersing the α-conductor in molten NaCl, AgCl or in mixtures thereof, in liquid sulphur or other insulating materials melting at a temperature of about 1000 degrees. The solid α-conductor may be also embedded by sintering the same in a previously pulverized insulating material, if desired, with the aid of chemical reactions in the interior of the insulating material.

As material for the wires or ribbons of the α-conductor of which the negative resistors are made it is preferable to use highly refractory oxides as CuO or UO_2. The oxides are preferably at first pulverized and before or after the body is given the final shape sintered in an annealing furnace in a suitable atmosphere at such a high temperature as to result in a completely homogeneous material. The desired conductivity or characteristic of the α-conductor may be also attained by giving the wires or ribbons of suitable metal the shape required for a negative resistor and by causing them to form compounds by chemical reactions, which compounds are suitable to bring about the descending characteristic of the α-conductor. This method has the particular advantage in that a completely homogeneous and reproducible structure of the α-conductor may be thereby attained. Moreover, it is preferable in the case of α-conductors containing oxides to treat the insulating material before embedding the α-conductor therein in an oxidizing or reducing atmosphere depending upon the desired oxygen content of the α-conductor, provided this is possible without exceeding the required percentage of the oxide in question in order that the chemical potentials of the oxygen in the insulator and in the α-conductor approach one another, thus preventing a change in the oxygen content of the α-conductor during the thermal embedding process.

The above-described measures, particularly as to the embedding process and dissipation of heat, may also be advantageously applied under certain circumstances to resistors which are made of conducting powder which is pressed but which does not represent a completely homogeneous conductor according to the invention.

I claim as my invention:

1. A resistor with a descending characteristic, comprising a conductor having a negative temperature coefficient, said conductor consisting of a solid, homogeneous, coherent material and

having the diameter of its current-traversed cross section of a size approximately 1/10 mm. and less, an insulating enclosure covering the side surfaces of said conductor, and metallic electrodes of relatively large proportions with respect to those of said conductor, said electrodes being secured to said conductor at its end faces and having at their surfaces contacting said conductor a larger diameter than said end faces, said insulating enclosure and said electrodes being disposed for dissipating the heat produced within said conductor, chiefly by heat conduction.

2. A resistor with descending characteristic, comprising a conductor consisting of a homogeneous, solid and coherent material of negative temperature coefficient and having the shape of a cylinder of approximately equal transverse and axial dimensions, and electrodes consisting of massive metal bodies of good heat conductivity intimately connected with the end faces of said cylinder, said electrodes having at their surface contacting said cylinder a transverse dimension greater than that of said cylinder.

3. A resistor with descending characteristic, comprising a conductor consisting of a homogeneous, solid and coherent material of negative temperature coefficient and having approximately equal transverse and axial dimensions in the magnitude of approximately 1/10 mm., and an electrode consisting of massive metal bodies of good heat conductivity intimately connected with each of the two end faces of said conductor, said electrode having its surface contacting said end face greater than said end face so as to transversely extend over said end face.

4. A resistor with descending characteristic, comprising a conductor consisting of a homogeneous, solid and coherent material of negative temperature coefficient and having the shape of a cylinder of approximately equal transverse and axial dimensions, electrodes consisting of massive metal plates of good heat conductivity intimately connected with the end faces of said cylinder and having a transverse dimension considerably greater than that of said conductor, and an insulating enclosure disposed on and firmly connected with the cylindrical surface of said conductor between said electrodes.

5. A resistor with descending characteristic, comprising a conductor consisting of a homogeneous, solid and coherent material of negative temperature coefficient and having transversal and axial dimensions of similar magnitudes, and two electrodes consisting of metal of good heat conductivity intimately bonded with the end faces of said conductor, said electrodes being of extremely great mass and size as compared with said conductor and having at their surface which contacts said conductor a transversal extension considerably greater than said end face of said cylinder.

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