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METHOD OF MAKING AN ELECTRICAL RESISTOR

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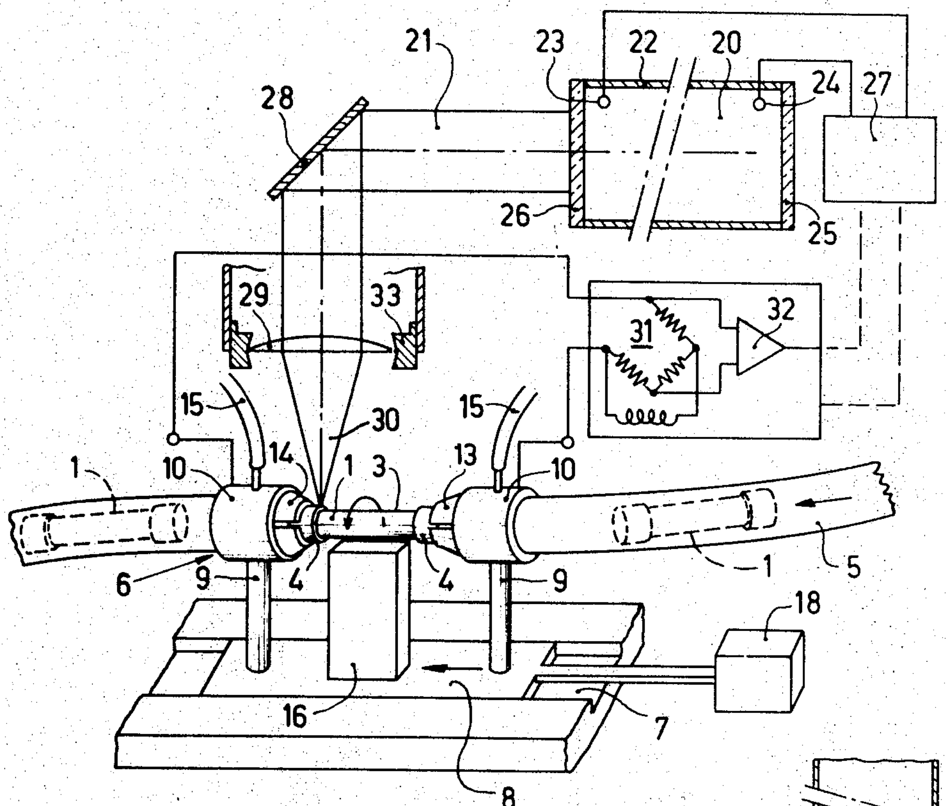

FIG. 1

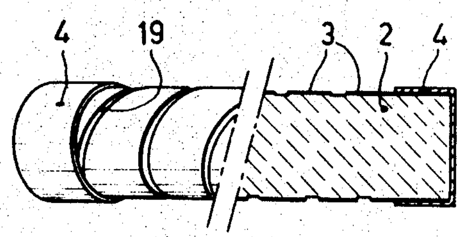

FIG. 2

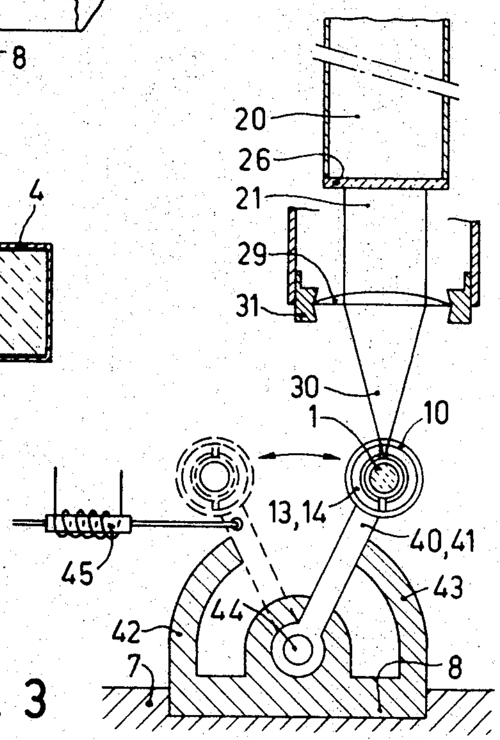

FIG. 3

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METHOD OF MAKING AN ELECTRICAL RESISTOR

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ABSTRACT OF THE DISCLOSURE

A method of using a laser beam of removing resistance material along a helical path on the outer layer of a resistor to obtain a predetermined resistance value.

This invention relates to a method of processing a resistor body, in which resistance material is removed along a helical path from a resistance layer applied to a cylindrical carrier consisting of insulating material and provided at each end with a connecting cap, until the electrical resistance between the caps acquires a predetermined value; and it also relates to an electrical resistor having a resistance layer which has been processed in this manner.

In the most common method of this kind, the resistance material is removed along the path by means of a fast-rotating grinding disc with a sharp edge which is moved in the axial direction along the resistor body that is held in a rotary holder. This method has the disadvantage that the edges of the path being ground are crumbly rather than sharp, resulting in a limit being set to the minimum pitch that can be used. Furthermore, during the grinding process the resistance material is liable to expand over the basic surface of the groove ground in the carrier, so that the resistor ultimately obtained may become voltage-sensitive. Another disadvantage inherent in this grinding method is that the helical path cannot be made to adjoin directly a terminal cap, with the result that the resistance variation obtainable by the grinding process is less than in the case where the groove could be made to adjoin a terminal cap.

These disadvantages are avoided in another known method of the above-mentioned kind in which the resistance material is removed with the aid of an electron beam focused onto the layer. However, this is offset by the fact that this other method requires the use of a comparatively bulky equipment, and that the resistor body to be processed, together with the means of producing the electron ray, has to be placed in vacuo. Furthermore there is the risk that, when using high accelerating voltages for the electron ray, X-rays are produced and an electric charge is injected into the carrier, which may cause damage to the surface of the carrier.

An object of the invention is to provide a method of the above-mentioned kind in which the disadvantages of both methods above described are avoided.

The method according to the invention is characterized in that the resistance material is removed along the path by means of an electromagnetic beam of rays having an energy of at least several watts and which is focused onto

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the resistance layer and that, upon relative displacement of the resistance layer and this beam, the beam is continuously emitted by a device for producing the beam by stimulated emission. An advantageous form of the method according to the invention is characterized in that the beam is produced in a device having a gas-discharge space filled with a gas consisting of a mixture of carbon dioxide, nitrogen and at least one of the gases helium and steam, the wavelength of the radiation in the beam being in practice 10.6 microns, while the discharge space is closed by a window occupying almost the entire cross-section, which window is made of a material permeable to infra-red radiation and is at the same time a reflecting member.

It should be noted that in the manufacture of metal film resistors with a very small tolerance, it is known first mechanically to cut a helical path into a metal layer vapour-deposited on the inner wall of a glass tube, until an ohmic value is obtained which is approximately 0.5% lower than the ohmic value desired. Subsequently, metal is evaporated at the end of the helical path by means of a radiation beam which is periodically interrupted in time and obtained from an intermittently-operating device for producing a radiation by means of stimulated emission, the amount of evaporated metal being such that the resistance value obtained differs less from the desired value than the permissible tolerance. This method of manufacturing metal film resistors retains the disadvantage inherent in mechanically forming the helical path, while also the use of a beam of rays emitted intermittently requires succeeding impact areas to overlap if the material is to be removed over a continuous region. In the method according to the invention which utilizes a beam emitted continuously, a continuous portion of the resistance material is automatically removed. Consequently the velocity of movement between the focused beam and the resistance layer can be higher than would be possible with an intermittent beam for obtaining a continuous path.

In the above-mentioned advantageous embodiment the gas-discharge space may communicate with spaces for the supply and removal of gas. To minimize the space for the equipment required, it is advantageous to use a gas-discharge space which is closed in a gas-tight manner.

The present invention also relates to a device for carrying out the method according to the invention described hereinbefore. This device is characterized by a rotary holder for receiving a resistor body to be processed, a gas-discharge device closed in a gas-tight manner for continuously producing a beam of electromagnetic radiation having a wavelength of approximately 10.6 microns by stimulated emission, which device contains a gas consisting of a mixture of carbon dioxide, nitrogen and at least one of the gases helium and steam and is provided with an exit window for the beam; this window is permeable to infra-red radiation and is also a reflecting member. Also provided is means for focusing the emerging beam onto the resistance layer to be processed on a resistor body in the holder; and further means is provided for a relative displacement of the focus of the beam and the resistor body in such manner that the focus defines a helical path across the resistance layer.

In order that the invention may be readily carried into effect, several embodiments thereof will now be described in detail, by way of example, with reference to the accompanying diagrammatic drawing, in which:

FIG. 1 shows one embodiment of a device for processing a resistor body in accordance with the invention;

FIG. 2 shows, in part elevational view and in part longitudinal section, a resistor manufactured by this device according to the invention;

FIG. 3 shows a device similar to that of FIG. 1, but which slightly differs therefrom and is viewed in a direction transverse to that of FIG. 1.

In the form of the method according to the invention which will be described with reference to FIG. 1, resistor bodies **1** each comprising a cylindrical and preferably ceramic carrier **2** (FIG. 2), which is covered with a resistance layer **3** throughout its cylindrical surface and also has metallic terminal caps **4** pressed one onto each end, are supplied successively through a flexible tubing **5** to hollow, rotatably-arranged clamping members **13** and **14** of a clamping device indicated as a whole by **6**. The device is movable over a straight guide formed, for example, by a guide path **7**, and the device is formed by a carrier plate or slide **8**, which co-acts with the guide path **7** and on which two insulating supporting columns **9** are placed, possibly in a mutually displaceable manner, each of which ends into a metallic hollow sleeve **10**.

The clamping members **13** and **14** are rotatably supported in the sleeves **10** and placed in such manner that their axes are aligned in the direction of movement of the slide **8** over the guide path **7**; the distance between their adjacent ends lies between the distances which exist in the resistor body between the adjacent ends and the remote ends respectively, of the terminal caps **4** of a resistor body **1** supplied through the tubing **5**. The clamping members **13** and **14** can be opened and closed in the radial direction from without in a manner not shown, for example, by means of control air supplied through tubings **15**. A resistor body supplied via tubing **5** by means of compressed air, is centrally moved through the clamping member **13** until its front end, which is guided by a supporting plate or supporting groove **16**, finds its way into the clamping member **14** and is stopped there. This stopping may be caused, for example, due to the clamping member **14** having an inner collar which, in the half-open condition of this clamping member when a terminal cap **4** can be slipped into the aperture of the member **14** adjacent the clamping member **13**, further barricades the way to this cap but no longer forms an obstacle in the fully-open condition of the member **14**. A resistor body once being fed into the clamping device, the clamping members **13** and **14** are closed and caused to rotate by a driving device (not shown). It is to be noted that it suffices if only one of the clamping members **13** and **14** is driven. The sense of rotation is indicated in FIG. 1, when viewed from the left, in the clockwise direction. An object of the method according to the invention illustrated by the device of FIG. 1 is to remove along helical line material from the resistance layer **3** on a resistor body **1** held in the clamping device **6** in a manner which is more advantageous than known hitherto, so that the electrical resistance of the resistance layer between the terminal caps **4** of the body acquires a predetermined value. To this end, the device of FIG. 1 includes a device **20** for continuously producing a high-energy beam **21** of electromagnetic radiation having a wavelength of approximately 10.6 microns, the device **20** being indicated hereinafter as "iraser" for the sake of simplicity. The iraser **20** is formed by a fully closed discharge tube **22** filled with a gas mixture consisting of carbon dioxide, nitrogen and at least one of the gases hydrogen and helium. Inside the tube are two electrodes **23** and **24**, for example, of platinum, the electrical connections of which are led through the cylindrical part of tube **22**, which consists of quartz. This tube is closed at one end by a concave mirror **25** having a maximum reflection factor and at the other end where the beam **21** emerges, by a plane mirror **26** which transmits the radiation to a certain proportion, for example, 50%. When the electrodes **23** and **24** are connected to an adjustable voltage source **27** which can supply a voltage between 20 kv. and 30 kv., a radiation field is built up in the iraser **20** by continuously stimulated emission, resulting in the substantially parallel beam **21**. The beam **21**, which may have a diameter between 5 mm. and 10 mm. and which has an energy of at least several watts, for example 10 watts, is reflected towards the clamping device **6** by means of a plane mirror **28** and then concentrated into a narrow beam **30** having a minimum diameter between approximately 150μ and 250μ by means of a lens **29** made of, for example, intrinsic germanium and having a focal length of, for example, 5 cm. The axis of said beam is directed to the axis of the clamping members **13** and **14**, the lens **29** provided with anti-reflection layers being adjustable by means of an adjustable fitting **33** so that, if the point of intersection of said axes lies between the clamping members **13** and **14**, the smallest diameter of the focused beam **30** coincides more or less with that portion of the resistance layer on a resistor body held in the clamping members which is struck by the beam.

A resistor body **1** received in the clamping device **6** after being supplied through the tubing **5** is now processed by the beam **30** as follows: The slide **8** is coupled to a driving mechanism **18** shown diagrammatically, which displaces the slide **8** from an initial position in which the focused beam **30** is directed to that part of the terminal cap of a resistor body **1** held in the clamping device which projects from the clamping member **14**, at constant speed along the guide path **7** in the direction to the left in FIG. 1, so that the resistor body **1** is explored as it were by the focused beam **30** from the clamping member **14** towards the clamping member **13**. Since the resistor body **1** follows the rotation of the clamping members **13** and **14** present in the sleeves **10**, the beam **30** describes a helical line across the resistor body having a pitch which is given by the ratio between the rotational speed of the clamping members **13** and **14** and the speed of the rectilinear movement of the slide **8**. The material of the resistance layer **3** which is struck by the beam absorbs energy from the beam **30**, this material thus being locally evaporated, which process is determined not only by the conversion of heat supplied to the surface of the resistor body **1**, but also by the velocity of movement of the resistance layer **3** relative to the beam **30**. The terminal caps **4** consist of a metal having a thickness of 0.1 mm. or more, which is thus great relative to the depth of penetration of the beam of rays. The cap to which the beam **30** is directed at the beginning of the processing thus absorbs so little energy from the beam that it is not influenced. However, as soon as the beam **30** leaves the cap due to the relative movement of the resistor body **1** and the beam, the local removal of the resistance layer begins. This local removal takes place along a steadily lengthening, helical narrow path **19** which adjoins the relevant cap (see FIG. 2), whereby the electrical resistance between the terminal caps **4** of the resistor body is raised. As the path **19** is being formed, this resistance is measured with the aid of a measuring bridge **31** in a measuring device **32**, which is electrically connected to the sleeves **10**. The measuring device includes means which are not shown but known per se, which provides an indication signal when a predetermined resistance value is reached. This indication signal is used to stop the processing of the resistance layer **3** on the resistor body in the clamping device **6** and also to initiate further manipulations for the purpose of feeding a subsequent resistor body **1** through the tubing **5** to the clamping device **6**.

The processing of the resistance layer **3** by the beam **30** may be stopped in different ways, for example, by switching off, wholly or in part, the electrical supply for the iraser **20**, which is shown in FIG. 1 by an electrical connection for a control signal between the measuring device **32** and the supply voltage source **27**, or intercepting the beam **30** or the beam **21** by means of a screen which is movable, for example, electromagnetically and which transmits the beam of rays only to a limited extent, if at all. For the same purpose, an electrically controllable light valve, such as a Kerr-cell, can be used.

A third possibility is neither to switch off the iraser wholly or in part, nor to intercept the beam of rays emerging therefrom, but to ensure by tilting the mirror **28** or displacing the lens **29** in the axial direction, for example upwards in FIG. 1, that the beam **30** insofar it can still strike the resistor body **1**, is defocused locally to such an extent, that the material of the resistance layer **3** is no longer influenced because of the low energy density. The indication signal from the measuring device **32** is also used in a manner not shown in FIG. 1, to reverse the movement of the slide **8**, so that the slide returns to the initial position shown, and is used further to open the two clamping members **13** and **14** so that the resistor body **1** just processed is removed through a flexible tubing connected to the member **14**. Furthermore a subsequent resistor body is supplied through the tubing **5** to the clamping device **6** and held in it to undergo thereafter a similar processing as the previous resistor body which has in the meantime been removed. The whole process can be automated without fundamental difficulty.

As an illustrative example can be mentioned that, if the resistance layer **3** consists of a carbon layer of approximately 1,000 Angstrom thick which has been deposited in known manner by dissociation of a hydrocarbon compound, the beam **30** if having an energy of approximately 25 watts permits of forming in this resistance layer a continuous helical path **19** having a width between 150μ and 200μ at a velocity of approximately 0.5 metre per second, that is to say the velocity of the relative displacement of the resistance layer **3** and the focused beam **30** may be 0.5 metre per second.

A resistor body **1** which has been processed by the device of FIG. 1 is shown in FIG. 2, in which **19** indicates the helical path along which the material has been removed from the resistance layer **3** by the beam. The width of this path, which may be, for example, 200 microns, is adjustable by adjusting the lens **29**, that is to say by focussing the beam **30** more or less sharply on the resistance layer **3**. The method described affords the advantage that the edges of the remaining portions of the resistance layer which bound the path **19** are smooth and hence not crumbly, such as occurs in grinding.

Furthermore, the surface of the carrier **2** is clean and smooth at the path **19**, the surface of the ceramic carrier **2** has fused in situ and the molten material may slightly cover the edges just mentioned. All these factors contribute to obtaining good reproducibility of the method and to advantageous electrical properties of the resistor manufactured. Due to the smoothness of the edges bounding the path **19**, this path may be given a pitch which is lower than is permissible in the known grinding method. This implies that, starting from resistor bodies having specific dimensions and a given resistance layer, the greater possibility of varying the pitch as well as the direct connection of the path **19** to the terminal cap permits of obtaining an assortment of resistors of different ohmic values which is larger than that obtainable with the known grinding method.

With respect to the known method of forming a similar helical path in the resistance layer by means of a focused electron ray, the method according to the invention affords several advantages: There is no need to work in vacuo, considerably lower operating voltages are permissible, resulting in a less bulky equipment, greater energy densities can be used without a risk of X-rays ocurring, so that the rate of processing can be increased, which is advantageous for bulk production.

FIG. 3 shows diagrammatically a portion of a device which differs from that of FIG. 1 only in a few details, the same reference numerals having been used for corresponding elements. The rotary clamping members **13** and **14** are now fitted on insulating supporting arms **40** and **41** which can rotate about a spindle **44** supported by the

slide **8**, through an angle bounded by stop cams **42** and **43** and in a plane transverse to the axis of the resistor body **1**. In the one position of the supporting arms the resistor body **1** finds itself wholly outside the beam **30**, in the other position the said beam is exactly focused on the resistance layer **3**. The processing of this layer by means of the beam **30** can be stopped in this device in a similar manner as in the device of FIG. 1. A further possibility is the use of an electromagnetic operating device **45** coupled to the supporting arms, which device is controlled by the indicating signal from the measuring device **32** and then pushes the resistor body **1** as it were out of the beam **30**. In the device of FIG. 3, the iraser is arranged transversely instead of parallel to the direction of movement of the slide **8**. The mirror indicated by **28** in FIG. 1 may then be dispensed with.

It should be noted that, if the relative displacement of the beam **30** and the resistor body **1** in the axial direction of the latter as is necessary in the method described is not unduly large, this displacement may be effected in a manner other than that above described by shifting the lens **29** in the said direction, whereby the slide **8** remains in place and need not be designed as a slide.

The material referred to above for the resistance layer **3** is carbon. However, the method acording to the invention is not limited thereto. Thus the resistance layer **3** may consist of metal, such as nickel or nickel chromium, insofar the metal layer is not unduly thick. On the one hand there must be sufficiently absorption of energy, which is obtained in thin layers due to the surface of the carrier **2** absorbing the radiation of the beam **30** transmitted by the metal layer, on the other hand the local thermal capacity and dissipation of heat must not be such as to prevent the temperature rise necessary for the evaporation of the metal. To form a metal-free path of approximately 200μ wide, a nickel-chromium layer of approximately 1000° Angstrom thick can excellently be processed in the described manner by the beam **30** having an energy of 30 watts at a velocity of movement of the beam across the nickel-chromium layer of approximately 0.5 metre per second.

What is claimed is:

1. In a method of processing a resistor body initially formed of a resistance layer upon a cylindrical carrier consisting of insulating material with a connecting cap on each end, the improvement in combination therewith comprising: (a) directing along a helical path on said resistance layer an electro-magnetic beam of rays continuously emitted by a device for producing the beam by simulated emission, (b) focusing the beam onto the resistance layer, (c) relatively displacing the resistance layer and the beam to traverse said path, and (d) thereby removing resistance material along said path until the electrical resistance between the caps acquires a predetermined value.

2. A method as defined in claim **1** wherein the beam is produced in a device having a gas-discharge space filled with a gas consisting of a mixture of carbon-dioxide, nitrogen and at least one of the gases helium and steam, the wavelength of the radiation in the beam being approximately 10.6 microns, while the discharge space is closed by a window occupying almost the entire cross-section, which window is made of a material permeable to infrared radiation and is at the same time a reflecting member.

3. A method as defined in claim **2** wherein the gas-discharge space is closed in the gas-tight manner.

4. A method as defined in claim **1** wherein the resistance layer consists of carbon deposited on the insulating carrier.

5. A method as defined in claim **1** wherein the resistance layer is formed by a metal layer, for example, a nickel-chromium alloy, having a thickness between approximately 20 Angstrom and 3000 Angstrom.

6. A method as defined in claim **1** comprising the further step of varying the energy of the beam upon the resistor body at the beginning and end of the method.

7. A method as defined in claim 6 comprising the further steps at the beginning and termination of the method of defocusing the beam such that a transition occurs on the resistance layer.

8. A method as defined in claim 1, further comprising, directing the beam to one of the caps prior to removing the material from the resistance layer.

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