Dec. 20, 1966 P. ROBINSON 3,293,587

ELECTRICAL RESISTOR AND THE LIKE

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Fig.1.

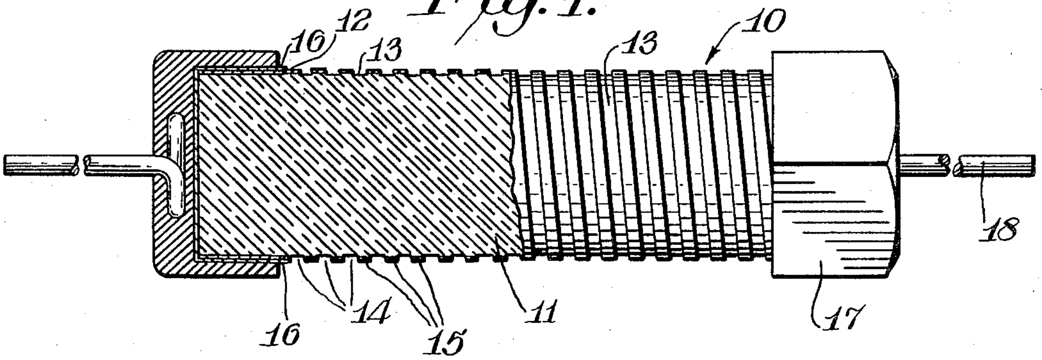


Fig.2.

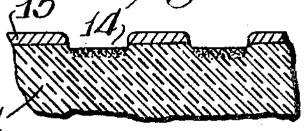
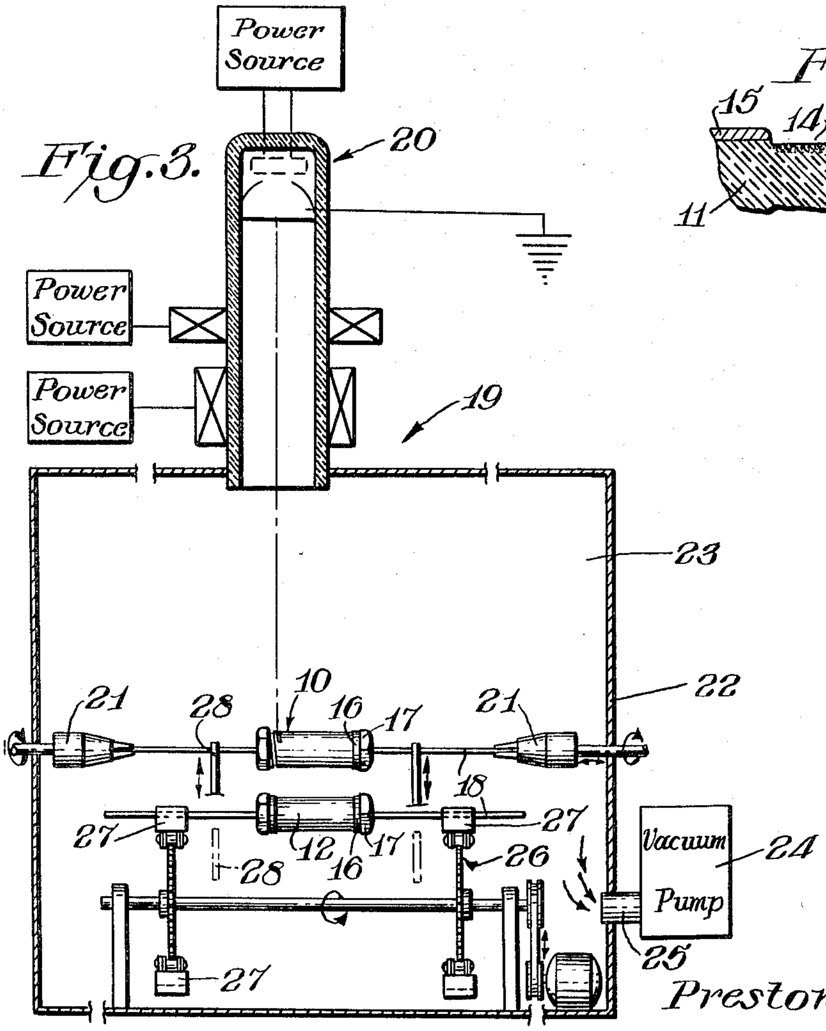


Fig.3.



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ELECTRICAL RESISTOR AND THE LIKE

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Continuation of abandoned application Ser. No. 262,626, Mar. 4, 1963. This application Oct. 20, 1965, Ser. No. 506,426

2 Claims. (Cl. 338—300)

The present application is a continuation of application Serial No. 262,626, filed March 4, 1963, now abandoned which in turn is a continuation-in-part of application Serial No. 807,247, filed April 17, 1959, now U.S. Patent No. 3,080,481, issued March 5, 1963. The last-mentioned application is a continuation-in-part of application Serial No. 553,893, filed December 19, 1955, now U.S. Patent 2,883,554, granted April 21, 1959.

This invention relates to surface film type resistor devices and the like, and to the apparatus and method for making them.

There are various types of surface film devices including resistors and inductances to which this invention may be applied. Among such types are the resistors of the metal film type in which the resistor element comprises a ceramic base which has been coated with a thin film of conductive metal and spiraled with a non-conducting strip to provide the final resistance. The invention may also be applied to an inductance wherein a conducting material is coated on an elongated base and the conducting turns are produced by cutting a helical path between turns of the conductive area.

Rapid production of resistors and other semiconductive devices and inductances presents problems in reproducibility, accuracy and flexibility. Resistances in such devices have tended to show variances from specification, and rejected units resulting from mechanical damage to the resistance element during production are undesirable. The temperature coefficients of resistance and of expansion in the surface film type of resistor affect the stability thereof. Therefore, in electrical circuits requiring a high stability of resistance values over a wide temperature range, a surface film type resistor produced by rapid production may vary from specified limitations because of the mechanical damage to the conducting film.

One of the problems encountered in producing a spiraled surface film type device is the time and effort involved in creating the insulating groove or cut which produces the lengthened conductive element of the device. The conventional means for producing this nonconducting spiral groove is a grinding operation using a sharp Carborundum grinding tool which knifes into the substrate through the surface film. The speed of forming the non-conducting groove in this manner is limited and consequently the integration of the production of surface film type devices into automated production is hindered. Moreover, the grinding technique makes an incision into the substrate to a considerable depth in order to surely and effectively provide the necessary separation between the turns of the conducting material. This deep incision introduces into the resultant device objectionable features which must be overcome. For example, the opening made in the device by the grinding will have a tendency to collect contaminants unless this is compensated for.

An important feature of the surface film type of resistor is stable operation at a high wattage rating. This requires an effective dissipation of heat equally along the whole length of the resistor. Where the dissipation of the heat is uneven and the temperature gradient along the surface of the resistor is high, there is a detrimental effect on the stability of the resistor. Moreover, it is desirable to provide the highest possible wattage rating for a given hot spot temperature in a resistor.

It is an object of this invention to provide a resistor or semiconductor device by rapidly forming non-conducting portions between conductive turns.

It is another object of this invention to provide a technique for the preparation of resistor or semiconductor bodies in a simple manner which accurately reproduces identical completed devices.

It is a further object of this invention to provide an electrical resistor having a rapid and even dissipation of heat.

Still another object of this invention is to provide a resistor having good electrical stability over a wide temperature range.

A still further object of this invention is a surface film type resistor with a helical groove having lower temperature coefficient of resistance than previously available.

Another object of this invention is to provide rapid helixing of a surface film type device to permit integration of the helixing in an automated process.

Still another object of this invention is the removal of a portion of the conductive film in a surface film type device without cutting substantially into the substrate.

These and other objects of this invention will become more apparent upon consideration of the following description taken together with the accompanying drawing in which:

FIG. 1 is an enlarged scale axial sectional view showing a construction in accordance with the invention;

FIG. 2 is a fragmentary axial sectional view of a portion of the surface of the construction of FIG. 1; and

FIG. 3 is a diagrammati section of apparatus for making a device of this invention.

The resistors of the present invention are coated with a layer of resistive or semiconductive material deposited on an elongated non-conducting base. The conducting layer is formed into a conducting track by a helical insulating path formed around the non-conducting base. The helical non-conducting path is produced on the device through the action of a focused beam of electrons on the coated base to cause the formation of the lengthened resistive path of the conducting track.

A surface film type device as referred to herein includes metal film resistors in which a non-conducting base such as a ceramic rod is coated with a metal film and thereafter a nonconducting strip is formed by taking away part of the conducting coat in a helical path around the rod. This results in lengthening the resistive path of the remaining conducting material. The conductive material has a resistivity and this resistivity provides the resistance value of the ultimate product. Conductivity and resistivity as used in reference to the surface film type device are relative terms. For example, resistivities can range from below 10^{-3} ohm-cm. to about 10^{6} ohm-cm. for silicon, illustrating that in principle a wide range of resistances are possible for this chemical element. Moreover, a satisfactory resistor can be produced with 1 ohm-cm.

silicon. It is thus seen that semiconductivity and resistivity have similar connotations.

Referring to FIG. 1, there is shown a resistor unit **10** of this invention in which an insulation core **11** is shown with a peripheral metal film element **21** in spiral convolution on a surface **13** of the core **11**. The helical shape is produced by removing the resistive or semiconductive material of film **12** in the manner of thread cutting. A non-conducting path **14** is the result of helixing and separates turns of the film **12** and forms a portion of the film **12** into a conducting track **15**. The film **12** is originally deposited on the surface **13** of the ceramic core **11** to which it bonds firmly. End terminations **16** are of noble metal in order to insure low contact resistance with the resistance film **12**. Metal end caps **17** and leads **18** are provided at either end. The end caps **17** are in contact with the end terminations **16**.

The enlarged view of FIG. 2 serves to illustrate the insulation of the successive turns of the conducting track **15** by the intervening turns of the non-conducting path.

The steps of providing the helixed resistor **10** comprise first coating the ceramic core **11** with the resistive film **12** and thereafter helixing the coated core **11** by evaporating the non-conducting path **14** under the impingement of an electron beam. The resultant evaporation rapidly removes the material of film **12** as the resistor **10** is rotated on its axis while the electron beam is scanned along the length of resistor **10**. This results in a lengthening of the resistive path and hence an increase in resistance value. The core is initially coated to give an initial value R*i* and and thereafter the helical non-conducting path is formed extending along the length of the resistor **10** until the desired final resistance value R*f* is attained. The helixing process is carried out automatically, the resistor being rotated on its axis while at the same time the electron beam is advanced at a constant speed along the length of the resistor **10**. The increase in resistance is measured as it occurs by integral circuitry and means are provided for detecting the attainment of a given value and for instant cessation of the helixing.

The apparatus for treatment of the resistor is shown in FIG. 3. A vacuum electron beam device **19** uses an electron beam generated from a triode gun in any convenient manner from a source as indicated at **20**. Such source can, for example, be of the type described in British Patent No. 714,613. It provides a beam which is focused so that it converges at the site of a resistor **10** as shown in FIG. 3. The resistor **10** is held in chucks **21** which are rotated by suitable driving means not shown. As shown, the chucks **21** seize the leads of the resistor **10** and hold the resistor **10** in the electron beam.

An air-tight housing **22** forms a chamber **23** which contains the resistor **10**, the chucks **21**, and mechanisms for moving a succession of resistors into engagement by the chucks **21**. The electron beam source **20** mounted in conjunction with the housing **22** is arranged to direct the beam into the chamber **23** and impinge it upon the resistors **10** while they are rotated by the chucks **21**. A conventional vacuum pump **24** connected to the chamber **23** through a conduit **25** serves to evacuate the chamber **23** and provide vacuums down to any desired pressure such as 0.1 micron.

A suitable mechanism for advancing and positioning successive resistors **10** is indicated in the chamber **23**. The illustrated mechanism is comprised of a chain belt conveyor **26** moving a plurality of paired yokes **27** for engaging the leads **18** of individual resistors **10**. The advancing yokes **27** move resistors into position for elevation to the chucks **21**. Forks **28** are suitably actuated by means not shown to lift the resistor leads **18** and elevate the resistors **10** from the yokes **27** to the chucks **21** for the electron beam treatment and then subsequently to lower the resistors **10** back to the yokes **27**. The chucks **21** are connected by circuitry not shown, so as to be part of the resistance means measuring circuit described below and are also connnected to ground through circuitry not shown.

In this invention a surface film type device, and more particularly a resistor, may be helixed by mounting a coated body having a surface film of suitable resistive or semiconductive material on a pair of yokes **27**, advancing the yokes by the chain drive **26** into position for engagement by the forks **28** and moving the resistor up to be gripped by the chucks **21**. The chucks **21** are then rotated and the electron beam employed to remove a strip of the material to produce the non-conducting path **14**. The chamber **23** is evacuated by the suction pump **24** connected to the conduit **25** and this evacuation can also serve to remove the vaporized products from the chamber and thus continue to preserve the electron beam efficiency. When the chamber **23** is evacuated by means of the pump **24**, the electron gun of the electron beam source **20** is energized and the accelerated electrons emitted into the chamber **23** are focused by magnetic fields as indicated in FIG. 3, the electron beam impinges on the rotating surface of the resistor **10** and heats the material of film **12** in a localized area to result in its vaporization.

The apparatus can handle any material that vaporizes and the temperature can be carried to any desired degree. The width of the beam is readily adjustable by the focusing means of the electron beam source and accordingly the width of the nonconducting path **14** is adjustable. The beam is made to scan along the length of the resistor **10** by the focusing means. In fact, the width of the cut can be adjusted during the helixing of a single unit and the pitch of the path **14** can be adjusted by the speed of the scan and the rate of rotation.

The conducting track can, for example, be less than 5 mils wide, and the nonconducting path at least as wide as the conductive path. Three mils is a typical width for both the conducting and non-conducting tracks. An entire ¼ watt resistor can be not over ½ inch long.

The start of the nonconducting path is accurately controllable as is also the ending or the termination of the cut of the nonconducting path. These operations are simply achieved by either deflecting the beam onto or away from the resistor **10** or by focusing or defocusing at the precisely appropriate instant in time.

The electron beam impinging on the film **12** of resistive or semiconductive material causes the material to be evaporated and causes the substrate core in the area of the nonconducting path to be glazed by fusing of the ceramic which takes place under the impingement of the beam. The surface of the nonconducting path, therefore, is microscopically smooth.

The electron beam removes the conductive coating completely vaporizing the metal film material in an accurate path and striking the exposed substrate, heats it momentarily to the fusing point so that just a skin of glazed material is formed. The surface of the non-conducting path, therefore, is free from irregularities and imperfections and microscopically smooth. It is also defined by the edges of the conducting track which are extremely straight and parallel and free from all irregularities. The electron beam, in removing the material along the non-conducting path, makes a very shallow cut into the substrate.

This cut is preferably to the depth of less than 0.0005″. The lateral edge formed by the conducting track and the shallow groove is gently rounded to provided a smooth flare with no sharp edges.

The electron beam source is used to remove the resistive or semiconductive material in a path by evaporation. The electron beam source is preferably operated at a high potential of the order of 15 or 20 kv. An electron beam current can be produced which causes the resistive or semiconductive material to evaporate under the impingement of the beam of the semiconductive material. This evaporation can be carried on in such a way as to rapidly remove the resistive or semiconductive material and thus form the non-conducting path. The steps of this procedure can be programmed into an automatic operation.

The electron beam current may be of the order of 90 microamperes and the beam power of the order of 2 watts. The current is subjected to a very sensitive grid bias control. The electron gun has the essential parts of a triode, with a grid bias of −90 v. A representative current out of the gun is 100 microamperes. To cut off the electron beam it is possible to increase the grid bias to −150 v. This will serve to cut the current down to below 1 microampere.

The means of controlling the electron beam provides a technique for a quick response to a signal for electron beam termination. The formation of the nonconducting path lengthens the resistive path of the conducting track and produces progressively an increase in resistance value. It is desirable to achieve, within a narrow average deviation, an exact final resistance value for the resistor. This is accomplished by providing a resistance measuring circuit which serves to measure the resistance value of the helixed device while the helixing is being carried on. When the final resistance value is achieved by the formation of the nonconducting path, the electron beam is cut off. The time between the resistance determination and this cut off has been cut down to as little as 10 milliseconds.

In the operation of the apparatus of FIG. 3 for the treatment of the resistive or semiconductive material and the formation of the helixed resistor, the resistor **10** is lifted from the yoke **27** on the forks **28** and placed in the chucks **21**. The chucks **21** seize the resistor leads **18** and holding the resistor **10**, rotate it axially. The electron beam is switched on and focused by adjustment to give the desired impingement on the material. This beam impingement is similar to that described in application Serial No. 807,247. The beam modifies the resistive or semiconductive material by evaporating a path. The path is formed by the axial rotation of the resistor and the deflection of the beam along the length of the resistor to trace a helical path of evaporated material forming the nonconducting path.

The pressure maintained in the chamber is controllable and may be carried down to an extremely high vacuum such as 0.01 micron. Gases generated within the chamber are removed by evacuation.

The electron beam source is produced according to conditions set forth in application Serial No. 807,247. This electron beam is introduced into the apparatus **19** through the opening and penetrates into the chamber **23**. The electron beam can be focused and can be aimed. Such focusing and aiming is shown in the above-mentioned British Patent No. 714,613. The resistor body with the resistive or semiconductive material is mounted in the chucks **21** within the chamber **23**. The resistor **10** is then subjected to treatment by the electron beam, as described. After the steps of treatment, the resistor **10** is removed by release from the chucks **21** into the forks **28** which lower it to a yoke **27**. While this treatment is being carried out, suction pumps attached to the ducts create a reduced pressure in the chamber and remove gases produced in the chamber.

As mentioned above, the beam scans the length of the resistor. Individual points on the surface of the resistor are subjected to the beam for from 3 to 5 milliseconds. The nonconducting path is traced with the combined scanning and rotation at a rate of the order of 150″ per minute to provide a resistor cutting rate of the order of 1 per minute. Such tracing at a rate of at least 100″ per minute works very well.

In one aspect of this invention the substrate material making up the ceramic core is beryllium oxide. Beryllium oxide is not useful as a substrate core for a helixed surface film type device produced by conventional methods because of the toxicity of the by-products from the worked beryllia material. Beryllium oxide is a highly desirable substrate in this type of resistor, as it assists in providing a high wattage rating for a given hot spot temperature in a resistor. The dissipation of heat generated in this of resistor is considerably greater at the two ends. The end caps and leads are factors in providing this greater heat dissipation. Moreover, the heat is generated mainly in the helixed portion rather than in the unhelixed end portions. Accordingly, the temperature distribution along the surface is uneven so that the maximum temperature or hot spot is in the central area with the temperature falling off at either end. In the beryllium substrate device the heat is most rapidly conducted away by the thermal conductivity beryllium substrate material. Accordingly, the resistor stays nearer to a uniform temperature and the rise of temperature in the resistor above the ambient is limited or maintained at a minimum.

Ceramic metallic films may provide desirable surface films for this type of device but present problems in the technique of adjusting the resistance value for an ultimate useful product. The ceramic metallic material after application to the nonconducting base is tenaciously adhesive to the base. The resistance adjusting technique of this invention is particularly applicable to this problem. For example, a cermet of 65% chromium and 35% silicon monoxide as a surface film can be readily adjusted to a desired final resistance by the means and method described herein. Another good resistance material made useful as an adjustable surface film by this invention is molybdenum disilicide.

The above-described invention and its preferred embodiment and the use thereof may be more completely understood by the following example given to illustrate the invention and not intended to be limitative.

EXAMPLE

A resistor having a resistance of 1300 ohms was formed by coating a steatite core with a nickel alloy resistive material, applying a gold terminal at each end, and attaching tin solder caps. The resistor was rotated on its axis at a rotational speed of 175 r.p.m. in a vacuum of 0.1 micron. An electron beam having a beam current of 90 microamperes produced from a beam-producing device under an accelerating voltage of 20 kv. with a grid voltage of −75 v. was impinged on the coat of the resistor and swept along the length of the coat in eight seconds. The beam vaporized a helical path in the coat and increased the resistance of the resistor to 2 megohms with ¼ wattage.

A flat substrate carrying a conductive film may also be treated with the electron beam apparatus in the evacuated chamber. The resistance of the conductive film may be adjusted by vaporizing portions of the film to produce non-conducting portions. The resultant non-conducting portions have a smooth surface even though they are made up from the substrate after removal of the conductive film.

Great flexibility may be obtained in the electrical values of the product due to the mobility of the electron beam and the speed of its operation on the coated substrate.

Another product of this invention is a surface film type inductor. A surface inductor is made of a conductive film such as either silver or copper deposited on an elongated round or bar-like non-conducting base and formed into a number of closely spaced turns of a conducting track by a non-conducting path produced in the metallic coat by impingement of an electron beam. As in the case of the resistor described above, the conductive material removed to provide the non-conducting path is volatilized and removed from the vacuum furnace by suction.

An advantageous example of an inductance prepared according to this invention is the provision of a silver coat on a magnesium oxide core. The silver coat is transformed into a helical conductor by forming a non-conducting path with the electron beam. The magnesia core and the silver conducting track coordinate through their similar coefficients of expansion to provide a well matched unit. The silver conducting layer is particularly adapted to effective cutting by removal with the electron beam.

In a modification of this invention a resistor body is provided having a ceramic substrate carrying a film of resistive or semiconductive material and overlain with a layer of ceramic to form a covering. This body can be helixed according to this invention to provide a helical surface film resistor. The non-conducting path can be cut from this body by the electron beam in the same manner as described above for forming the non-conducting path in the above described embodiment. The electron beam vaporizes and removes the overlying layer of ceramic at the non-conducting path. In this way a ceramic coating can be provided before the formation of the helix. Any possibility of contamination during the step of applying the coating is thus avoided. A feature of the product of this method is the small percentage of exposure of the resistor material during and after the path cutting operation. Only the cut edge of the resistive material is exposed and as the exposed edge is almost dimensionless, actually it is not sensitive to exposure.

According to an additional optional step in the treatment of the resistor, the resistor may have a protective surface applied by polymerizing a gas in the chamber for deposit on the resistor after the cutting of the non-conducting path **14** is complete. The chamber may hold a gas which when subjected to the electron beam will result in the application of a protective layer to the semi-conductive material. In FIG. 1 the resistor **10** shown in axial cross section is shown to have a resistive or semi-conductible material of the film **12** removed according to the process of this invention by the electron beam evaporation and apparatus of FIG. 3 in the non-conducting path **14**. The removed portion of the material **10** is the result of removal of the resistive or semi-conductive material by direct evaporation. The electron beam source **20** operates at a sufficiently high potential so that the effect of its impingement on the semiconductive material of the film **12** results in an evaporation of the semiconductive material by directing the beam against the path **14**. This path is removed from the film **12** as indicated by FIGS. 1 and 2. To effect this evaporation the resistor **10** is positioned in the chucks within the chamber under a reduced atmosphere to cause the electron beam to be projected against it without undue loss of efficiency. Suction pumps evacuate the chamber. The electron beam from the beam source strikes the resistor **10** and is focused by previous adjustment to give the desired beam impingement. An electron beam source operates at a sufficiently high potential so that the effect of its impingement on the resistive or semiconductive material of film **12** results in an evaporation of the semiconductive material by directing the beam along the path **14**. This evaporation is carried on in such a way as to rapidly remove portions of the resistive or semiconductive material of the film **12** and thus change its shape to the conducting track **15**.

After the removal of the material **12** from the non-conducting path **14** the resistor **10** is subjected to the next step of resistor manufacture. This may include the application of the protective coating.

An important advantage of the electron beam helixing is the smooth edge of the path when it is cut. This smooth edge results from the melting. In the first place, the profile has a much reduced curvature surface. With the mechanical method a jagged edge is formed. This is undesirable since it produces sharp points which can be areas of concentration. These areas of concentration are points at which break-down can start. The shape and stability of the conducting path are important. The electron beam provides a very even or smooth edge conducting path. (This is demonstrated in the control of the magnetic field at the edge of a superconductor. In a superconductor if the flow along the edge is not disturbed by the irregularity of the edge, the superconductive phenomenon is preserved. Therefore with the electron beam method of cutting, a smooth edge is provided so that the conducting path has the desired straight shape and is stable and preserves the superconductivity.)

Among other advantages this invention provides a precise resistor having resistive values within a close tolerance, including resistors having a tolerance of as low as 1/10 of 1%. The effective narrow cut of the non-conducting path provided by this invention permits a great reduction in size of the metal film resistor for the same value. Correspondingly, there is provided a considerable increase in wattage rating for the same size unit.

Another advantage is the stabilized temperature coefficient of the resistance permitted by the good heat dissipation made possible. Moreover, it is possible to match a core and a coat having compatible temperature coefficients of expansion.

A most important advantage is the faster helixing with fewer rejects which makes this invention particularly adaptable to automatic production. This is particularly so because of the lower noise in the resultant unit due to the cleaner cut of the non-conducting path and the lack of damage to the substrate.

The electrode beam apparatus as disclosed herein provides a means for adjusting the electrical values of the surface film device very precisely. The resistance measuring means, which has a fast response for terminating the grooving upon the attainment of the desired resistance, permits extremely precise control of the product.

The groove or cut which makes up the non-conducting turns, is smooth and has a sharp boundary with the microscopically smooth, straight edge of the conductive material. These features provide a surface which is not conducive to entrapment of contaminants. A second advantage of the foregoing grooving technique is provided in the modification which employs a ceramic coat over the metal film before the helixing takes place. With the ceramic coat in place and the non-conducting path cut through the coat, the helixing produces a device which needs protection only over the extremely thin edge of the metal film. Thus the production is expedited and simplified.

The flexibility of this means and method will also be appreciated. It will operate on any material or combination of materials that vaporize. It is thus effective in making helixed surface film devices with hard-to-handle materials that have other extremely advantageous properties. The characteristics of the resultant product are correspondingly improved. Another facet of the vaporizing in a vacuum aspect of this invention is found in the advantage gained from being able to process in the vacuum materials otherwise unavailable for use because of their toxicity. Beryllia, for example, is generally unattractive as a material but can be safely used according to this invention.

The above-described embodiments and particularly the embodiment treating a resistive metal alloy film on a steatite Al Si Mag 513 rod, have been found to be effective in practice. However, without departing from the spirit of this invention various modifications may be made as exemplified in the modifications indicated above, and therefore it is intended that the invention be limited only by the scope of the appended claims.

What is claimed is:

1. A resistor having a cylindrical ceramic member carrying on the outside of its cylindrical surface a number of closely spaced turns of helical electrically conductive coating of metallic electrical resistance material in which the side edges of the turns are microscopically smooth and straight, the surface of the ceramic member being glazed in the spaces between turns and recessed below the ceramic surface on which the turns are coated, the coating having end terminations between which the turns are connected.

2. The resistor of claim **1** in which the end terminations of the coating are adjacent the opposite ends of the ceramic member, each end is encircled by a terminal connector, and a stratum of noble metal at these ends cooperates in connecting the terminal connectors to the coating ends.

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