The invention described herein may be manufactured and used by or for the United States Government for governmental purposes without the payment to me of any royalty thereon.

The present invention relates to a vapor-plating apparatus and particularly to a device for accomplishing vapor deposition upon an unpowered heated surface, especially in the form of a continuously moving strip or filament of indefinite length.

In the art of vapor deposition or vapor plating, it has been the practice to establish a vapor-laden atmosphere of the plating material around the object or substrate to be plated. Most generally, the substrate has been heated to a sufficiently high temperature that the vapor will undergo a gas-phase reaction at the heated surface to form a pyrolytic coating thereon. Particular emphasis of late has been on such vapor plating of fine filaments which are heated by the passage of an electric current therethrough while the filament is in or passing through a vapor chamber. Because such filaments in the order of thousands of feet in length are desired, the art has focused its attention on means for continuously heating and plating upon a section of the wire as it moves continuously from a supply reel through the vapor chamber and onto a storage reel.

In the formation of such continuous filaments however, the prior art has encountered serious difficulties in applying the electrical current to the moving wire substrate and in handling it as it becomes heated. These problems have included, among others: the provision of a highly resistant, or a very fine filament, on the order of a fraction of a mil in diameter, has been desired, in that the heating required to insure the gas-phase plating reaction has in most cases diminished the tensile strength of the substrate to the point that it will yield or break under the stresses required to move it through the vapor chamber. It has been found however, that as the substrate progresses through the chamber and the coating builds up in proportion to the exposure time of the filament to the plating atmosphere, the strength of the filament is increased to the extent that a higher voltage or greater electric current may be applied thereby yielding a higher surface temperature and more favorable plating conditions without however causing breakage of the filament. This discovery has suggested the desirability of applying successively increasing voltages or electrical currents across segments of the conductive substrate within and progressively inwardly of its entrance to the plating chamber.

A basic apparatus for accomplishing this steadily increasing segmented heating comprised a series of pairs of electrical contacts, across each of which successively increasing voltages could be separately applied. Such contacts, connected to an electrical power source by conventional wiring means first comprised conductive metallic surfaces with which the moving substrate could make sliding contact. Later they took the form of tubing ends or other housings for a pool of mercury, the reservoir dimensions of which could be selectively altered to force the mercury beyond the tube end to provide a meniscus through which the filamentary substrate could pass and, by its contact with the electrically conductive and electrically charged mercury, be made to carry an electric current and thereby become heated.

Attempts to place such electrical contacts within the vapor chamber as required to benefit from this successively increasing segmental heating of the substrate led however to substantial difficulties which have heretofore prevented the otherwise desirable application of such a technique. Chief among the problems thus arising has perhaps been the loss of uniformity of the deposited coating not only as to its thickness and resultant outside diameter of the coated filament but also with regard to a variety of the physical properties of the coating itself such as its crystalline structure, density, porosity, purity, its adherence to the substrate, its coherence and the like.

Another significant problem that arose in connection with electrical contacts internally of the vapor chamber, particularly where heating was to be accomplished by an alternating current, was the tendency of the filamentous substrate so charged to oscillate or vibrate. This resulted not only in premature breakage of the filament as it was being plated but also in separation of the filament from engagement with the contacts resulting in arcing. This arcing was also a problem in all of the prior art contacts, particularly those relying upon metal-to-metal engagement, and produced deleterious effects upon the quality of the coating plated out. But even where the aforementioned difficulties were avoided the operation was unpredictable and the uniformity of the product was haphazard indeed.

It is accordingly an object of this invention to provide an improved vapor plating apparatus.

It is another object of the invention to provide such an apparatus wherein the plating will be deposited upon an electrically heated surface.

Still another object of the invention is to provide such an apparatus which can vapor plate a filament of indefinite length as it passes continuously through a vapor chamber.

Still another object of the invention is to provide an apparatus wherein the electrical heating may be applied via a plurality of electrical contacts with the filamentary substrate as it passes within the vapor chamber.

Still another object of the invention is to provide such an apparatus capable of yielding a vapor-plated substrate wherein the coating or film deposited thereon is uniform both as to size and as to physical and chemical properties.

Still another object of the present invention is to provide such an apparatus wherein arcing will not occur between the substrate and the electrical contact even where alternating current is employed.

These and other objects and advantages which will be apparent from a reading of the following disclosure are achieved in the case of the present invention by the provision of special means for applying the heating electrical currents directly to the substrate at various points within the vapor chamber, and this while the substrate is moving therethrough. It has been found that the advantages herebefore mentioned arising from the application of steadily increasing voltages through such contacts may be achieved without any attendant loss in the quality and uniformity of the end product where the contacts are in the form of a mercury meniscus provided by means which include expendents for controlling the temperature of such meniscus.

From the provision and use of such a device, it has been learned that if the mercury approaches a temperature equal to that of the substrate with which it is in contact, not only will the mercury tend to vaporize and enter into a contaminating reaction with the substrate but also will its heated surface accumulate quantities of the deposited vapor in the form of slugs or impurities which
will ultimately attach to the substrate and interfere with uniform plating thereon.

To provide a uniform and non-arcing contact between the electrical connection and the moving substrate which has not been heretofore available in the prior art, the present invention includes the features of a sliding solid-to-solid contact with the mercurial meniscus by placing a metallic sliding surface, preferably in the form of a metal ring at a point in the mercurial meniscus at which it may be completely wetted by the fluid.

In a modification of such a device particularly adaptable to the temperature control of the meniscus, the metallic sliding surface is in the form of a metal ring of copper, aluminum, or the like, generally circular in cross section, and is attached, preferably by a high-heat-transfer connection or joint such as silver solder to a flat annular disc presenting an annular broadside surface which is adjacent or effectively near the heat or temperature control means. In combination with this sliding ring within the meniscus is a wire guide in the form of a metallic loop in a plane perpendicularly disposed to the slide and urged in the direction of said slide in said plane by a weight associated with the appropriate stirrup which may surround the mercury tube or housing at the open end of which the meniscus is provided. The weight maintains the ring submerged in the mercury since the specific gravity of mercury is 13.546. Without the weight the ring would float on top of the mercury.

The invention thus generally described may be more clearly understood by reference to the following detailed description of certain preferred embodiments thereof in connection with which reference may be had to the appended drawings.

In the drawings:

FIG. 1 is an elevational diagrammatic view in partial cross section of an apparatus according to this invention for vapor plating an indefinite length of an electrically conductive filament passing continuously therethrough;

FIG. 2 is an enlarged fragmentary elevational view in partial cross section of a preferred form of electrical contact unit for applying an electrical current to a continuously moving substrate in a vapor plating chamber or environment;

FIG. 3 is an enlarged fragmentary elevational view in partial cross section of the contact of FIG. 2 shown as having been rotated through 90 degrees.

Referring now to FIG. 1, the substrate is in the form of a filament 10 of an electrically conductive material such as metal; e.g., tungsten, copper, etc. and, in one specific example it may be a finely drawn tungsten wire on the order of .005 inch in diameter. Such a substrate is caused to pass from a supply reel 11 through the vapor chamber 13 to take-up or storage reel 12 by a variety of driving mechanisms, usually primarily dependent upon the motion of the take-up reel 12 but often involving a correlation of the driving movement of the take-up reel and the movement of the storage reel so as to control the tension upon the filament, particularly at the critical stages of its being heated within the chamber 13. Filament seals 13a and 13b close the interior of the vapor chamber 13 to the ambient atmosphere. Since the wire need not be broken at any point within the chamber it may be handled in indefinite lengths and treated continuously as hereinafter described. Via the conduit 14 the chamber 13 may be supplied with a vapor laden with the desired platting material.

Where for example, it is desired to form a continuous pyrolytic graphite filament by the vapor deposition of carbon upon the tungsten wire filament above mentioned, the vapor chamber 13 may be supplied via the conduits 14 with a rich hydrogen feed such as a hydrocarbon gas; e.g., methane, or a vapor formed by bubbling or similar passage of a carrier gas through a hydrocarbon liquid. In the formation of such pyrolytic graphite filaments, the temperature of the tungsten wire should be raised to the order of from 2,000 to 3,500 degrees Fahrenheit to cause the vapor to undergo a gas-phase reaction at the hot wire surface and thereby to "plate out." To bring the wire 10 to such a temperature rapidly and gradually increasing segments as it progresses from the entrance 13a of the chamber to the exit 13b thereof, the wire 10 engages the electrodes 15, 16, 17 and 18, across each pair of which is supplied an electrical current which is separately controlled by manipulation for example the variable resistances 19, 20 and 21 in the circuits connecting the terminal pairs 15 and 16, 16 and 17, and 17 and 18, respectively.

To enhance the precision of the segmentally increased heating, to require a minimum number of electrodes and to avoid excessively high voltages, it has been found desirable to join successive electrodes to form electrode pairs and then to connect the pairs to the power source 22 by isolation transformers such as 19a, 20a and 21a along with the variable resistance devices. With the secondary coil of the transformers connected as shown, it can be seen that the interiorly positioned electrodes 16 and 17 may act both as the end of one segment and the beginning of another segment of the substrate over which a different voltage and heating current will be applied.

A further advantage of the illustrated wiring is available where alternating current is applied to the transformers in such a phase relationship that, at a given instant, the electrical charge (positive or negative) at the end of any secondary coil will be similar to the charge at the adjacent end of the next successive coil. In such an arrangement, the voltages of each segment will tend to "buck" each other so that the total voltage across the entire apparatus will be only the net difference between the voltages applied across each pair of electrodes. Since, as will be hereinafter described, the electrodes each comprise a substantial quantity of mercury, the electrical connection between the power supply and the electrode may be by a variety of conventional wiring means in contact with or immersed in any part of the mercury.

The structural refinements of the terminals such as 15, 16, 17 and 18 are illustrated in FIGS. 2 and 3 wherein a typical electrical contact according to the present invention is shown to comprise the mercury-containing tube or housing 25 characterized at its upper extremity 26 by a well or orifice 30 from and above the confines of which the mercury may be controlled to rise and to form the meniscus 27. The effective size of the mercury-containing tube 25 and well 30 may be controlled by a pinching or clamping of the lower end thereof or of a tubular extension 28 thereon which is radially deformable (by virtue of its elastomeric composition, for example) by a suitable clamp 29.

The result of a reduction of the effective size of the mercury-containing components is the forcing of the mercury higher in the tube and an elevation of the meniscus above the surface of the tube end 26. Subject to the considerations to be hereinafter discussed, the mercury reservoir should be so manipulated as to provide a projection of the mercurial meniscus a sufficient distance beyond the tube end to completely cover or "wet" the substrate-accommodating components and to provide an unencumbered quantity of mercury through which the substrate may pass.

Surrounding the mercury supply within the tube 25 and the well 30 is a cooling jacket which, in the embodiment illustrated, is in the form of the concentrically aligned passages 31 and 32 separated by the tubular member 33 so as to provide for the flow of a coolant such as water upwardly through the inner passage 31 and downwardly through the outer passage 32 while at the same time absorbing and removing heat that is building up in the meniscus as a result of its contact with the heated wire 10. Examination of FIGS. 2 and 3 will disclose that the mercury supply and cooling apparatus might be considered as comprising three concentric tubular members 25,
8,318,269 5 33 and 34, wherein the upper ends of the inner and outer tubular walls 25 and 34 respectively are connected by the closing wall 35 spaced from which is the upper extremity of the tubular member 33 so that fluid can flow between this tubular member and the closing wall 35.

To provide the mercurial reservoir in the form of the well 30 thereby allowing for more precise control of the meniscus height by restriction of the tubular extension 28 and to improve the cooling capacity by increasing the heat-transfer surface, the closing wall 35 may be upwardly and outwardly flared from the inner tubular member 25 as illustrated.

At the upper extremity of the mercury supplying and cooling portion of the apparatus is positioned a horizontally disposed component to serve as a slide against which the filament or substrate to be coated may rest and across which it may move. In the specific embodiment illustrated, such a slide member is shown to comprise the flat disc or washer 36, affixed to the upper broadside surface of which is a film of molecular thickness, the entire upper surface of the disc. Additional advantages, particularly with regard to the purity of the plated coating are achievable where the configuration of the slide, for example the relative sizes and position of the washer 36 and the ring 37, is such that the meniscus boundary intersects the filament-contacting line provided by the ring or other sharp extension or protuberance from the sliding unit.

It has been found that the filament slide so positioned and constructed will have the beneficial effects on the plated product of uniformity of size as well as of physical and chemical properties.

It is theorized that the causes of these beneficial results include the line contact of the unit with the substrate afforded by the sharp definition of the slide washer as opposed to the less firm confines of the liquid meniscus. At the same time, it is believed that the effect of the thermally conductive washer is to more sharply define the boundary between the vapor plating hot zone within the chamber and the relatively cooler electrical contact so that vapor deposition can occur upon the substrate only while it is removed from the contact as a result of which contaminates do not occur in the plated coating.

Further improvement over the prior art devices is provided by the present invention in the form of a mechanism which appears for the first time to make possible the use of alternating electrical current as the heating medium for the substrate, the use of which in the past has been neglected because of the inability to obtain a reasonably uniform heating. The guiding mechanism taught herein for this purpose combines with the mercurial meniscus on the one hand and the filament slide on the other to prevent any separation between the filament and the electrical contact. It is believed that even though such separation was not apparent in the prior art uses of alternating current, it did actually occur as a result of the vibrations or oscillations induced in the filamentary substrate by the passage and cycling of the alternating electrical current therethrough. The guide according to the present invention is in the form of the ring or eylet 39 vertically disposed in a plane perpendicular to the plane of the slide components 36 and 37 and to the direction of travel of the substrate thereover.

As best illustrated in FIG. 3, the ring guide 39 is affixed to and suspended from the stirrup 40 which is characterized at its lower extremity by the cylindrical rider weight 41 which encircles and is slidable along the outer tubular member 34 so as to guide the vertical movement of the eyellet 39. Fixedly associated with the outer tubular member 34 may be the cylindrical seat 42 to provide an abutment surface which will limit the downward movement of the stirrup and of the guiding ring 39 associated therewith, while leaving the guide free to move upwardly in response to vibrations or other strains upon the filament passing therethrough.

The combined weight of the guide ring 39, the stirrup 40 and the rider 41 should be such however, that it will overcome any force tending to raise the filament from the contact and thereby constantly confine the filament to the mercurial meniscus. At the same time, the weight of the guide ring assembly is such as to restrain the filamentary substrate passing therethrough and thereby actually to prevent excessive vibrations. The permissible spacing between successive electrodes providing such substrate restraint is a function of the cross-sectional dimensions of the diameter of the substrate, the greater the cross section, the greater the allowable spacing between electrodes.

The result of the above described construction and arrangement of parts whereby arcing between contact and substrate is completely eliminated and proper electrical contact is maintained between filament and the heating power source is an apparatus which can be reliably predicted to provide a uniform, plated coating upon a substrate which will be free of foreign contaminates or other undesirable properties. Aside from the vibration damped mechanism above described, the achievement of these results is substantially aided by the cooling of the mercury contacts which renders them virtually inert to any vapor plating atmosphere on the one hand and prevents their volatilization to contaminate the plating atmosphere on the other hand.

Also believed to contribute substantially to the absence of contaminates in the finished product is the effect of the line contact between the electrical source and the substrate provided by the filament slide ring 39 immersed in the mercurial meniscus by the pull of gravity on the weight 41 through the stirrup 40, the unexpected observable result of which has been the confining of contaminates and deposits of material other than the plating material to the opening with the annular slide by what is probably a coating between the surface tension of the mercury and the ring. Such confinement it is observed, prevents the flow of the contaminates on to the substrate.

While the invention has been described herein in considerable detail and in connection with certain specific embodiments as required by law, it is to be understood that the foregoing particularization and details are for the purposes of illustration only and do not limit the scope of the invention as it is defined in the subjoined claims.

I claim:

1. An apparatus for continuously vapor plating upon a moving electrically conductive substrate comprising a vapor chamber, means for moving said substrate through said chamber, a plurality of electrical contacts, means for applying separate electrical currents to individual segments of said
substrate through successive pairs of said contacts thereby segmentally to heat the substrate as it passes through the chamber, wherein said contacts comprise a mercury reservoir, means for establishing and maintaining a meniscus projecting from said reservoir and contacting said substrate, cooling means for the mercury in said reservoir and said meniscus, and a wall defining said reservoir and wherein the structure of said wall is made hollow to thereby accommodate a circulating fluid which comprises said coolant means.

2. An apparatus according to claim 1 wherein said reservoir comprises a tubular portion characterized at an extremity thereof by an outwardly flaring well-defining wall above which said meniscus projects.

3. An apparatus according to claim 1 wherein said means for establishing and maintaining said meniscus comprise a deformable portion as a component of said reservoir and an adjustable clamp selectively operable for deforming such deformable portion.

4. An apparatus according to claim 1 wherein a thermally conductive disc is positioned within said meniscus and adjacent a portion of the wall of said reservoir with the opposite side of which said circulating coolant is in contact.

5. An apparatus for continuously plating upon a portion of a filamentary substrate of indefinite length while it is moving comprising a vapor chamber, a plurality of electrical contacts aligned and engaging said substrate within said chamber, each of said contacts comprising a mercury reservoir, means for maintaining a meniscus projecting therefrom, a contact slide of an electrically and thermally conductive material positioned within said meniscus and adjacent said substrate for sliding engagement therewith, means for electrically charging said mercury, and said slide is characterized by a relatively broad base having an upwardly projecting line-presenting portion to form a line of contact with said substrate.

6. An apparatus according to claim 5 wherein a cooling chamber is formed by a hollow wall structure defining said reservoir.

7. An apparatus according to claim 6 wherein said broad base is a flat annular disc and said upwardly projecting portion is an annular ring of circular cross section.

8. An apparatus according to claim 6 wherein the upper surface of said meniscus is maintained at a substantial intersection with said line-contacting portion.

9. An apparatus according to claim 5 comprising in combination with said meniscus and said slide, a guide ring in the form of an eyelet disposed in a plane perpendicular to the direction of movement of said substrate and immersed in said meniscus whereby said substrate passes through said ring and is confined thereby within said meniscus.

10. An apparatus according to claim 9 wherein said ring is held by a stirrup affixed thereto.

11. An apparatus according to claim 10 wherein said stirrup is associated with a weight to counteract movement of said ring perpendicularly of said meniscus.

12. An apparatus according to claim 11 wherein said stirrup will rest against an abutting surface fixed relative to said contact to limit its movement relative to said meniscus.

13. An apparatus according to claim 5 including means to vary the level of said meniscus.

14. An apparatus according to claim 13 wherein the means to maintain and to vary said meniscus comprises a mercury tube terminating upwardly in an opening, a deformable elastomeric extension downwardly of the mercury tube, and clamp means engaging the deformable tube extension for maintaining the mercury in the mercury tube with enough of the mercury exposed at the top of the tube for making electrical contact therewith.

15. The electrical contact comprising a plurality of concentric tubes, an innermost tube upwardly enlarged to provide a mercury well, disc means defining the top of the mercury well, a ring attached to the disc means, a deformable elastomeric extension tube attached to the innermost tube at its lower end, clamp means removably collapsing the deformable tube for the retention of mercury and for maintaining a desired mercury meniscus in the mercury well, temperature controlling tube means adjacent the innermost tube for the circulation of temperature maintaining means from outside the assembly through the temperature controlling tube, a weight seat secured to the outside of the temperature controlling tube at a position spaced downwardly from the upper end thereof, weight means removably resting on and supported by the weight seat, and stirrups secured at its lower end to the weight and extending over the top of the contact and down both sides of the temperature controlling tube.

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MORRIS KAPLAN, Primary Examiner.