

[54] **ELECTROFORMATION OF METALLIC STRANDS**

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[22] Filed: **May 31, 1974**

[21] Appl. No.: **475,098**

[52] U.S. Cl. **204/13; 204/208; 204/281**

[51] Int. Cl.² **C25D 1/04**

[58] Field of Search **204/208, 216, 281, 12, 204/13**

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[57]

ABSTRACT

A fine metallic strand of infinite length is produced by continuous electrodeposition of metal on a conductive strip having a narrow, closed-loop plating surface defined by an insulating material bonded to sides of the conductive strip so that the bonding surface is generally transverse to the plating surface. When a desired quantity of the metal is deposited on the plating surface, the strand is cut and one end is peeled off to a spooler. In one embodiment, the conductive strip and the associated plating surface have the shape of a double spiral.

22 Claims, 6 Drawing Figures

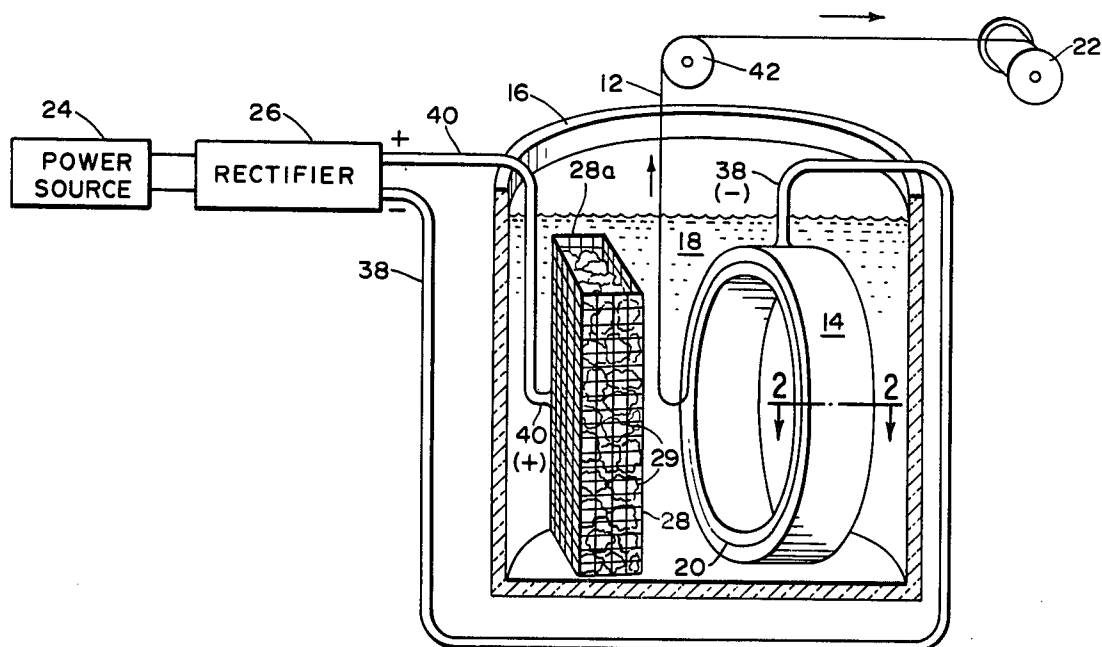


FIG. 1

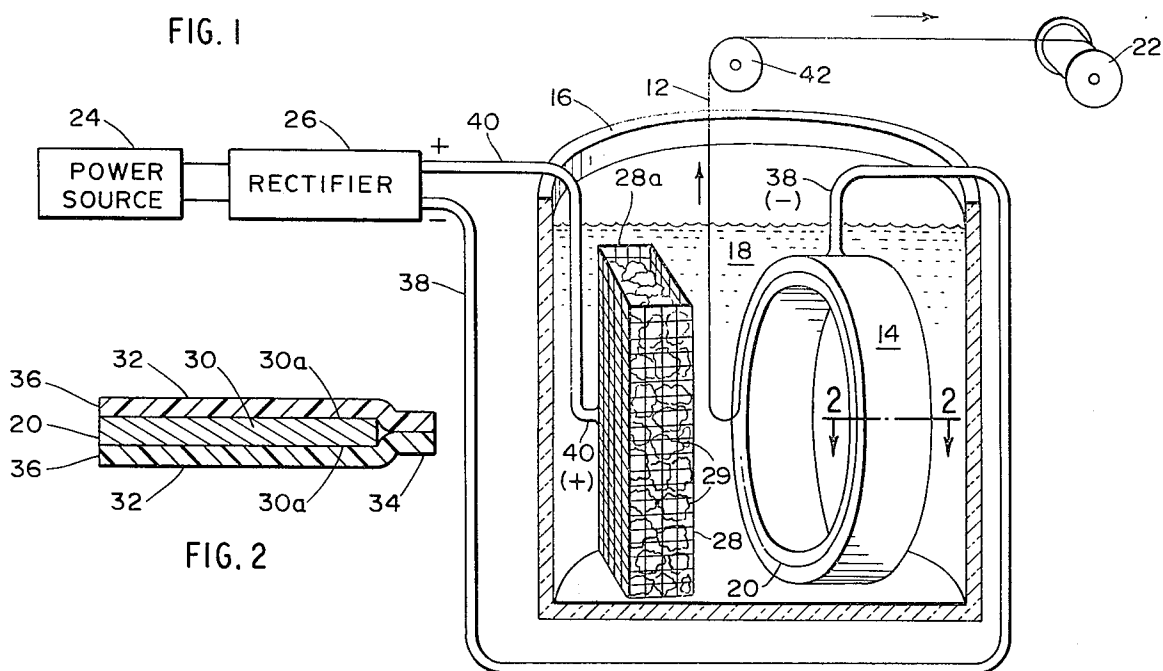


FIG. 2

FIG. 3

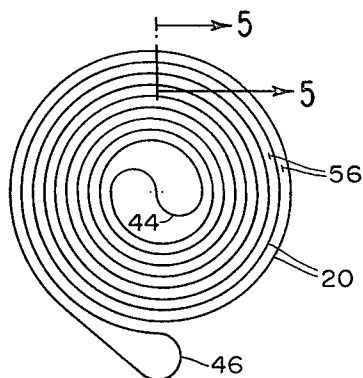


FIG. 5

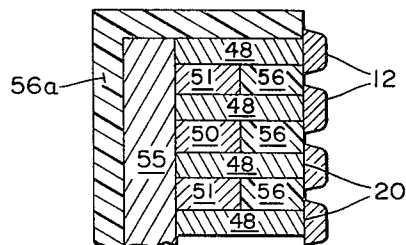


FIG. 4

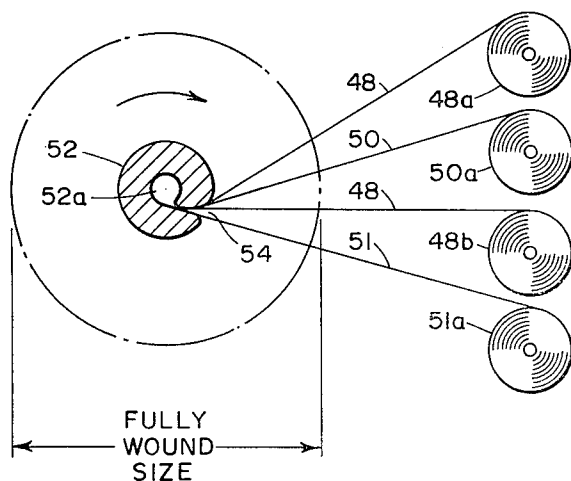
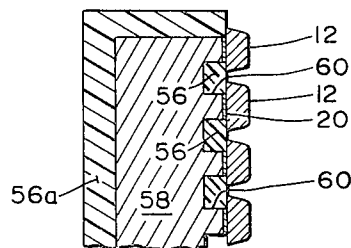


FIG. 6



ELECTROFORMATION OF METALLIC STRANDS

FIELD OF THE INVENTION

This invention relates in general to the production of metallic strands and more particularly to the continuous electroformation of fine metallic strands of infinite length.

BACKGROUND OF THE INVENTION

A well-known technique employed in the production of fine metal wires or strips involves the electrodeposition of the metal on a conductive cathode, followed by stripping and spooling of this electroformed wire. This process is particularly useful in the production of very fine strands having a small cross-sectional area since the production of such strands by a conventional drawing process is relatively slow and costly due, in part, to the large number of machines needed to implement a correspondingly large number of drawing operations.

A controlling factor in the electroformation process is the construction and shape of the cathode and its associated plating surface on which the metal is deposited. One type of prior art cathode has a flat plating surface with the deposit forming in one or more grooves scribed on it. The bottom of the groove is typically the conductive plating surface and the sides are a non-conductive material that serves to mask or confine the area of deposit and to provide a crude mold that assists in forming the desired cross-sectional shape. A common method of forming these grooves is to apply an insulating layer over a conductive surface and remove, for example, by scratching machining or similar techniques, a portion of the layer where it is desired to create the plating surface for electrodeposition. Conventional cathodes of this type do not, however, employ continuous plating surfaces, but rather, have a number of parallel, straight-line surfaces or a non-continuous curved plating surface such as a spiral. Such non-continuous plating surfaces necessarily produce segments of metallic strands each of which has a determinate, finite length corresponding to the uninterrupted length of the plating surface on which it is formed. These short strands are clearly undesirable for many applications such as the further processing of the strands into insulated or braided wire products.

Another type of prior art cathode utilizes a cylindrical cathode with plating surfaces in the form of spiral or circular grooves. Again, as in the flat surface cathode, the metallic strands produced with this spiral groove construction, cathodes are of a finite length. In contrast, a technique employing a circular groove construction is capable of producing strands of infinite length. U.S. Pat. No. 1,600,252 issued May 29, 1925 to C. K. Topping, for example, discloses a cylindrical cathode having a number of circular grooves formed on the surface of the cylinder and lying in parallel transverse planes. By immersing a portion of each circle in a plating solution and rotating the cylinder, it is possible to remove continuously a strand of infinite length from the circular groove as it leaves the solution. This production process suffers, however, from the disadvantage of being excessively slow since a rapid rate of strand production depends upon a rapid rate of cathode rotation, and the latter does not allow the relatively short plating path to remain in the plating solution long enough for sufficient amount of the metal to deposit.

An additional disadvantage of the prior art cathode structures is that they are subject to deterioration during frequent or continuous use. This problem is particularly acute when the masking insulation is in the form of a thin exterior layer bonded to an underlying conductive surface of either a flat or cylindrical geometry. In this situation, the insulating layer has a tendency, after repeated use, to separate from the conductive surface. During plating, some of the metal deposits in these separated regions or cracks. The metallic burr or ridge thus formed then impedes the removal of the strip from the plating surface and will frequently cause the strand to tear or deform as it is removed. Also, the thin masking edge of the insulating layer is highly susceptible to wear due to the abrasive action of the strand during its removal. This wear results in the formation of a strand that has irregularities in its cross-sectional dimensions.

It is therefore a principal object of this invention to provide an electroformation process for continuously producing a fine metallic strand of infinite length at a high speed and with a high degree of dimensional uniformity.

Another object of this invention is to provide an electroformation process that minimizes the deterioration of the masking insulation and eliminates the formation of burrs that project under the insulation.

Still another object of this invention is to provide an electroforming process that utilizes a stationary cathode and promotes an improved bonding between the conductive portions and the insulating portions thereof.

SUMMARY OF THE INVENTION

The electroforming process according to this invention utilizes a cathode having a closed-loop conductive portion forming a plating surface which is exposed to a plating solution. An insulating portion is bonded to the conductive portion at interfaces lying in a plane that is substantially perpendicular to the plating surface and is in continuous contact with the edges of the plating surface. A closed-loop layer of the metal to be formed, typically copper, is electrodeposited from the plating solution onto the plating surface. When the deposited metal reaches the desired thickness, the layer is cut and one of the ends formed by the cut is drawn away from the plating surface of the cathode to a spooler. Control of the draw rate and the electrodeposit rate produces a continuous strand having preselected cross-sectional dimensions. A cathode having a plating surface in the configuration of a double spiral offers an efficient utilization of the cathode area and an exceptionally high production speed.

DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a perspective view of one embodiment of a processing apparatus constructed in accordance with the principles of this invention;

FIG. 2 is a cross-sectional view along the line 2—2 of the cathode shown in FIG. 1;

FIG. 3 is a plan view of a double spiral cathode constructed according to this invention;

FIG. 4 is a schematic drawing illustrating one method of forming the cathode shown in FIG. 3;

FIG. 5 is a cross-sectional view along the line 5—5 of the cathode shown in FIG. 3 and constructed according to the method shown in FIG. 4; and

FIG. 6 is a cross sectional view corresponding to FIG. 5 of a double spiral cathode constructed according to this invention by an alternative method.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIGS. 1 and 2, a strand of metal 12 is formed on a cathode 14 immersed in a plating tank 16 containing an electrolytic solution 18. After formation, the strand is peeled from a plating surface or land 20 of the cathode 14 and directed to a spooler 22. A power source 24 and rectifier 26 supply a direct electrical current between the cathodes 14 and an anode 28. The cathode 14 has a closed-loop band 30 of a conductive material that is substantially inert or strippable with respect to the metal being plated. Layers of insulating material 32 are bonded to both side wall surfaces 30a of the band 30, leaving the edge of the band exposed as the plating surface 20.

In the cathode embodiment illustrated in FIGS. 1 and 2, the band 30 is a strip of a conductive material that has its ends welded or otherwise attached to each other to form a closed loop. The band material must be strippable with respect to the metal being deposited. As used here the term strippable excludes any material which would adversely affect the plating surface 20 or the metal being deposited, as well as materials which are physically reactive in the sense of a deposit which adheres so strongly to the plating surface that it renders the efficient removal of the strand 12 impractical. For example, in the electroformation of copper strands, suitable strippable materials include stainless steel, chromium, titanium, rhenium and molybdenum. Stainless steel is preferred for reasons of cost and availability.

As shown in FIG. 2, the cross-sectional shape of the band 30 is generally rectangular, with one edge forming the plating surface 20. The overall configuration of the illustrated band 30, and the associated plating surface 20, is that of a circle. However, a wide variety of configurations such as ovals, kidney shapes and more complex convoluted forms are equally practicable provided that they constitute a closed, continuous loop. Also, the cross-sectional shape can assume forms such as a trapezoid or triangle. The rectangular shape is preferred, however, since it is readily available as rolled stock and the edge surfaces 20 of such rolled stock are highly uniform and therefore particularly suited to the production of correspondingly uniform metallic strands 12.

The insulating layers 32 may be formed from any suitable material having the required dielectric, bonding and durability characteristics. The term "bonding" includes resiliency and/or thermal properties that maintain the bond over a range of temperatures, and the term "durability" includes withstanding the environment of a plating bath. Suitable insulating materials include epoxy resins, ceramics and plastics such as products marketed under the trademarks Lucite or Bakelite.

The insulating layers 32 are bonded to the broad "side" surfaces 30a of the band 30 leaving only the plating surface 20 exposed. Preferably, an oxide layer is formed on the side surfaces 30a prior to bonding in order to provide additional insulation and a stronger bond. Stainless steel may be oxidized, and molybdenum, rhenium or other metals may be coated with an oxide such as alumina. A metallographic press can then

be used for the actual bonding. In bonding, the opposed edges of the insulating material that overhang the band 30 join together in an insulated edge portion 34. One or both of these insulated edge portions is then ground off to expose the edge plating surface 20. The insulating layers 32 thus serve mask and define the plating surface 20.

A significant feature of this invention is that the insulating layers, and the bonding surface are substantially perpendicular to the plating surface 20. Further, if the insulating layers 32 should separate from the band 30, any metal that deposits in the separated region is automatically aligned in the general direction of the removal of the strand 12 from the surface 20. This reduces the likelihood of the strand shearing or deforming as it is removed and also markedly reduces the deterioration of the masking edges 36 of the insulating layers due to abrasion caused by the strand removal. The formation of an electrode of this structure can be accomplished without the requirement of scratching or machining grooves or paths in the face of an exterior insulating layer bonded over the plating surface.

FIG. 1 schematically illustrates one embodiment of apparatus to continuously produce fine strands 12 of infinite length in accordance with this invention. For purposes of illustration only, the operation is described with reference to the production of a copper wire. An insulated lead 38 that passes through the insulating layer 32 electrically connects an a.c. power source 24 and the negative terminal of the rectifier 26 to the band 30 and the plating surface 20. Another insulated lead 40 connects the positive terminal of the rectifier to the anode 28 which consists of a platinum wire basket 28a containing lumps of copper 29 which may be of a relatively low grade. The cathode 14 and anode 28 are immersed, in a spaced relationship, in the plating solution 18 of conventional composition. A suitable test solution included 240 grams per liter of hydrated copper sulfate and 39 cubic centimeters per liter of sulfuric acid, at room temperature.

With this arrangement, a layer of copper deposits on the plating surface 20. The rate of deposit depends in a well known manner on such variables as the area of the plating surface, the current density, and the concentration of the plating solution. Given a constant current density at the cathode, the amount of the deposit is directly proportional to the elapsed time.

The deposit assumes the shape of the continuous, closed-loop plating surface 20, with uniform parallel edges defined by the edges of the surface 20 and the insulating layer edges 36. In order to initiate the operation, the metal is allowed to deposit on surface 20 for a sufficient period of time to form a layer of the desired thickness and then a cut is made in the deposited layer. One of the ends thus formed is drawn away from the plating surface and directed in a well known manner over an idler wheel 42 to the spooler 22. The spooler then continues to draw and wind a continuous strand of copper from the plating surface. If the strand 12 is drawn onto the spooler 22 at a constant rate, and if the other variable parameters such as the applied current density are held constant, then the strand 12 will have a uniform cross-sectional area, except for the initial segment removed from the cathode corresponding to the length of one loop around the plating surface 20. This initial segment is generally thicker than the subsequent portion of the strand since, for the most part, it remains on the plating surface longer than any subse-

quent portion of the strand (the time for the initial formation of the first loop plus the time for its removal). In contrast, subsequent portions all remain on the plating surface for the same period of time, which is determined by the spooler draw rate (a constant for a given production run) and the length of a single, complete loop of the plating surface.

The production rate of this process and the cross-sectional dimensions of the strand being produced are interrelated, depending in part on the same parameters. Included among these parameters are the width and length of the plating surface. The width of the plating surface controls the width of the strand 12, and, other factors being constant, widening the plating surface lengthens the time required to deposit a layer of a given thickness. The length of the path influences the choice of the deposit rate, and determines, in conjunction with the draw rate, the amount of time a section of the strand 12 is on the plating surface. Another variable parameter, the draw rate, directly corresponds to the production rate. With other factors being constant, an increase in the draw rate produces the strand faster, but the strand will be thinner since it is removed from the plating surface in a shorter period of time. It should be noted that a plating surface having a long path length is advantageous since it allows a high draw rate while giving the strand time to deposit to an acceptable thickness of the metal. Other parameters affecting the production rate and strand dimensions are those controlling the deposit rate and include the current density at the cathode, the composition, concentration and temperature of the plating solution, and the condition of the plating surface. By way of illustration, a circular loop cathode 200 cm in length, 1 cm wide and having a plating surface edge 0.01 cm wide, placed in the solution described above, with a current maintained at 120 ma/cm², the initial strand deposits in 2 hours, and thereafter a strand having a cross-sectional area of 120 mils² can be continuously removed from the plating surface at a rate of 105 cm/hour.

The strand produced by this method generally has a rounded rectangular or trapezoidal cross section. For many applications, it is desirable to have the strand formed into a circular cross section. This can be accomplished by conventional drawing or swaging techniques. In particular, one or more reducing dies and pulling capstans can be placed before the spooler so that the spooled strand has the desired shape. Since the initial cross-sectional area of the strand is relatively small, the possibility of the strand shearing, deforming or developing strain points is reduced significantly.

FIG. 3 illustrates a preferred embodiment of a cathode suitable for the production of strands of infinite length in accordance with this invention. The illustrated shape of the plating surface 20 is a reverse or double spiral. This configuration can be visualized as being formed by spiral winding a long, continuous band having two closely spaced parallel sides each meeting in common end loops 44 and 46. Some significant advantages of this configuration are that (i) each complete loop around the plating surface is relatively long which permits a high production rate, (ii) the strand production per unit area of the cathode is high, and (iii) there are no sharp bends in the plating path which might interfere with the removal of the wire.

FIG. 4 illustrates in a simplified form one method for forming a reverse or double spiral cathode of the type illustrated in FIG. 3. A strip 48 of a suitable plating

surface material such as stainless steel and two spacer strips 50, 51 are wound simultaneously from supply rolls 48a, 48b, 50a, 51a, on a cathode hub 52. Each end of the strip 48 is wound on a separate supply roll (48a or 48b) and the interior end loop 44 is formed in a portion of the strip 48 that is intermediate the supply rolls 48a and 48b. A slot 54 in the hub allows the inner loop end 44 to be formed and supported in an open central portion 52a of the hub 52. A suitable method of forming the loop 46, and thereby making a closed loop plating strip, is to butt weld the outer ends of the strip 48 and accurately grind the weld joint to the same thickness as the strip. The edge or edges of this loop form the plating surface or surfaces 20.

With reference to FIGS. 3-5, the strips 50 and 51 are narrower in the dimension perpendicular to the plating surface 20 than is the strip 48, and they are centered during the winding process so that they are spaced uniformly from one or both edges of the strip 48, depending on whether it is desired to plate on one or both faces of the cathode. In the embodiment shown in FIG. 5, the spacer strips 50 and 51 are spaced only from the face shown bearing an electrodeposited strand 12. This spacing forms a groove between the spiral layers of the plating surface 20. Alternatively, the spacing strips can be the same width as the strips 50 and etched down to form the grooves. The etching process is facilitated if the spacer strips are copper or a material having similar etching properties. The use of a conductive metal as the spacer strip has the added advantage of enhancing the electrical conductivity throughout the body of the cathode. A copper backing layer 55 (FIG. 5) that is in electrical contact with all of the loops of the strips 48, 50, and 51 further enhances the electrical conductivity of the cathode.

An insulating material 56 is used to fill the grooves thus formed thereby masking the plating surface 20 in a manner similar to that of the layers 32 in FIGS. 1 and 2 and insulating the other conductive surfaces of the cathode. The insulating material 56 is applied in a viscous form which allows it to flow into and fill the grooves. The degree of viscosity required is determined principally by the dimensions of the grooves. Typical groove dimensions for the production of 34 AWG wire are a width of 20 mils and depth of 100 mils, separated by plating surfaces or lands having a thickness of 4 mils. For the production of 24 AWG strands, typical groove dimensions are a width of 50 mils and a depth of 100 mils, separated by plating surfaces having a thickness of 13 mils. In addition to these viscosity requirements, the insulating material must also have the characteristics of adhesion, thermal response or resiliency, and durability in the plating environment noted hereinabove with respect to the layers 32. A preferred insulating material is a low viscosity filled resin produced according to the following formula:

Composition	Parts
CIBA Araldite 1138	35
Dow DER 736	15
Hexahydrothallianhydride	37
Polyazelaic polyanhydride	6.50
Benzyltrimethylamine	0.75

Another suitable insulating material is a low viscosity filled resin manufactured by Emerson and Cuming under the trademark designation Stycast 2651 MM.

To apply the resin insulating material 56, the wound cathode is placed in a closed mold and sufficient resin is added to completely coat the cathode. The application of a vacuum and mild heating to the mold promotes the complete filling of the grooves and deaeration of the resin. When the grooves are filled, the resin is cured and the plating face of the cathode is ground and polished to expose the plating surface 20. Any cracks or irregularities are easily repaired by the application of more resin at these points. If the grinding exposes a portion of the copper spacer strips 50 or 51, they may be etched down and the area refilled with resin.

Alternative methods of producing a double spiral cathode include machining or photo-etching the desired pattern of grooves in a solid metallic substrate. FIG. 6 illustrates a cathode formed by photo-etching. A plate 58, preferably formed from stainless steel 316, is coated with a photoresist material on the surface (or surfaces) where it is desired to form the plating surface 20. This surface is preferably slightly roughened to enhance the adhesion of the photoresist material to the surface. The desired double spiral pattern is then exposed on the photoresist in a well known manner, the photoresist is processed, and the unexposed areas are subsequently etched in a conventional manner to form the grooves 60. A layer of a suitable strippable plating surface metal such as chromium is then plated or otherwise applied to the lands to form the plating surface 20. The insulating material is applied in the same manner as for the wound cathode. Finally, as with all the cathodes described herein, an insulated electrical connection is made to the cathode for introducing a uniform density current over the plating surface. In the embodiments illustrated in FIGS. 5 and 6, this connection is made to the copper layers 55 and 58, respectively, through the adjacent insulating layer 56a.

This description has disclosed a process and apparatus for the high speed electroformation of fine metallic strands of indeterminate length and highly uniform dimensions that utilizes a stationary cathode having a continuous closed loop plating surface and masking layers of insulation that are substantially perpendicular to the plating surface. Although this invention has been described with reference to cathodes having generally circular plating faces, it will be understood that the cathode may assume a wide variety of shapes provided that the exposed plating surface portion constitutes a closed loop. Further various modifications of the invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

Having thus described the invention, what is claimed is:

1. A method for continuously producing a metallic strand of indeterminate length, comprising the steps of
 - A. providing a cathode having a conductive portion with at least one exposed, narrow, closed-loop plating surface formed thereon, said plating surface being substantially strippable with respect to said metal, and an insulating portion in continuous contact with the edges of said plating surface and bonded to said conductive portions along a surface substantially perpendicular to said plating surface,
 - B. electrodepositing the metal on said plating surface with said plating surface totally immersed in a plating solution, and

C. removing the strand metal thus formed from said plating surface without interrupting said electrodeposition and without rotating said cathode.

2. The method according to claim 1 wherein said plating surface is substantially flat and has a constant width.

3. The method according to claim 1 wherein said cathode is stationary.

4. The method according to claim 1 wherein said conductive portion is a band having a generally rectangular cross section and said plating surface is an edge of said band.

5. The method according to claim 4 wherein said insulation portion is bonded to the sides of the band that are transverse to said plating surface.

6. The method according to claim 1 further characterized by an oxide insulating and bonding layer disposed between said conductive portion and said insulating portion.

7. The method according to claim 1 wherein said removing is further characterized by opening the closed-loop metallic strand formed on the plating surface when the strand attains a predetermined thickness, and drawing one on the ends formed by said opening away from said plating surface.

8. The method according to claim 1 wherein said removing is further characterized by

A. a first mode of operation comprising opening the closed-loop metallic strand formed on the plating surface when the strand attains a predetermined thickness, and drawing one of the ends formed by said opening away from said plating surface, and

B. a second mode of operation comprising continuing to draw the strand formed on the plating surface from the plating surface in a direction substantially normal to the plating surface, the point of the removal traveling continuously around said closed loop and drawing away the thickest portion of the layer deposited on the plating surface at a given time.

9. The method according to claim 1 further characterized by said electrodeposition and said removing having coordinated rates whereby said strand has a constant, predetermined cross-sectional area.

10. The method according to claim 7 further characterized by spooling said drawn end.

11. The method according to claim 7 further characterized by shaping said strand as said strand is drawn from said plating surface.

12. The method according to claim 1 wherein said closed loop path is circular.

13. The method according to claim 1 wherein said closed loop path is a double spiral.

14. A cathode for the continuous electroformation of metallic strands of indeterminate length, comprising, in combination,

a conductive base having a narrow, closed-loop plating surface formed on a first surface of the base, said plating surface being substantially strippable with respect to said metal, said plating surface having the general shape of a double spiral, and an insulating portion in continuous contact with the edges of said plating surface and bonded to said base along surfaces substantially perpendicular to said plating surface.

15. A cathode according to claim 14 wherein said conductive base comprises wound strips of a material substantially strippable with respect to said metal and

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alternating spacer strips, an edge of said spacer strips being spaced from said plating surface to form a groove.

16. A cathode according to claim 15 wherein said insulating portion is formed of insulating material filling said groove and said alternating spacer strips are formed from a conductive material.

17. A cathode according to claim 14 wherein said insulating portion is a filled epoxy resin.

18. A method for continuously producing fine copper strands of indeterminate length, comprising the steps of

A. providing a cathode having a conductive portion with at least one exposed, narrow, closed-loop plating surface formed thereon, said plating surface being substantially strippable with respect to said copper, and an insulating portion in continuous contact with the edges of said plating surface and bonded to said conductive portions in surfaces substantially perpendicular to said plating surface,

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B. electrodepositing the copper on said plating surface with said plating surface totally immersed in a plating solution,

C. opening the closed-loop strand of copper thus formed on the plating surface when the strand attains a predetermined thickness, and

D. drawing one end formed by said opening away from said plating surface without interrupting said electrodepositing and without rotating said cathode.

19. The method according to claim 18 wherein said plating surface is stainless steel.

20. The method according to claim 18 wherein said plating surface is chromium.

21. The method according to claim 18 wherein said insulating material is plastic.

22. The method according to claim 18 wherein said insulating material is an epoxy resin.

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