United States Patent

Lane

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[54] METHOD OF APPLYING A COATING

[72] Inventor: **George C. Lane**, Milford, Conn.

[73] Assignee: **Warner-Lambert Company**, Morris Plains, N.J.

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[52] **U.S. Cl.** **204/192,** 30/346.53

[51] **Int. Cl.** **C23c 15/00**

[58] **Field of Search** ....204/192, 298; 117/132 CF

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Primary Examiner—John H. Mack
Assistant Examiner—Sidney S. Kanter
Attorney—James F. Powers and Albert H. Graddis

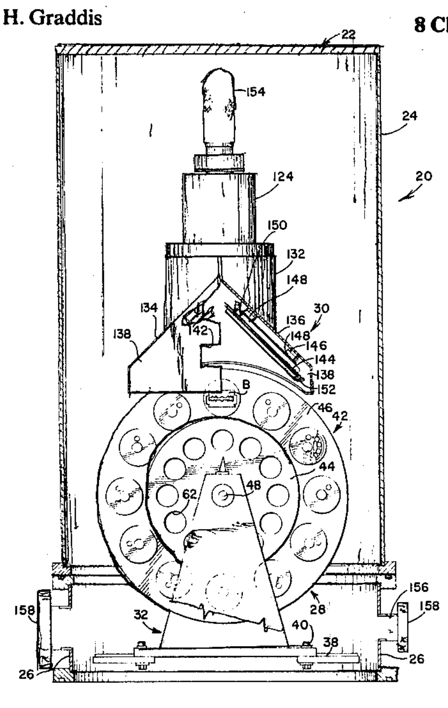
[57] **ABSTRACT**

An apparatus for applying a coating material to a substrate such as a razor blade, comprising a drum unit having a plurality of driven hub assemblies, each of which supports carrier means for carrying a large number of razor blades, and in which the hubs are driven, for example, by an epicyclic gear or chain mechanism, so as to expose the desired portions of the carriers, in a desired timed relation, to a coating material which is caused to emanate from a fixed source. The source comprises a so-called sputtering module including housing having, at the top part thereof, a pair of angled target plates from which the coating material is taken, and, at the bottom thereof, an opening past which the carriers are moved by the drum.

By "sputtering" as used herein, is meant the slow disintegration of a target under the bombardment of ionized gas molecules, and, more particularly, the disintegration of a coating material which is placed on the target and transferred to a substrate after being "sputtered" from the target.

The coating material is moved from the target plates to the substrate by a so-called "RF induced plasma sputtering," process. In this process, with the apparatus and materials in a very high vacuum, a high radio frequency, ("R.F.") is impressed across two electrode plates, each of which is disposed immediately behind the target plates, and each of which attains a high negative space charge. Thereafter, a normally inert gas, such as argon is introduced to the area between the plates, ionized, by bombardment with high velocity electrons, and the resulting plasma particles strike the target plates containing the coating material, freeing or "sputtering" it therefrom, in atomic or molecular sized particles, which are then attracted to the grounded potential substrate and are received and firmly bound thereon to form a coating of extreme smoothness and adhesion. In one embodiment, a metal coating is sputtered onto the edge portions of razor blades, and in other embodiments, organic polymers or other high-molecular weight coatings are transferred to a substrate, in some cases with simultaneous partial chemical breakdown, rearrangement, or other chemical or physical reaction during the sputtering process, and in still further embodiments, metal oxides, alloys, or other metal compounds are transferred, or simultaneously formed and transferred.

8 Claims, 8 Drawing Figures



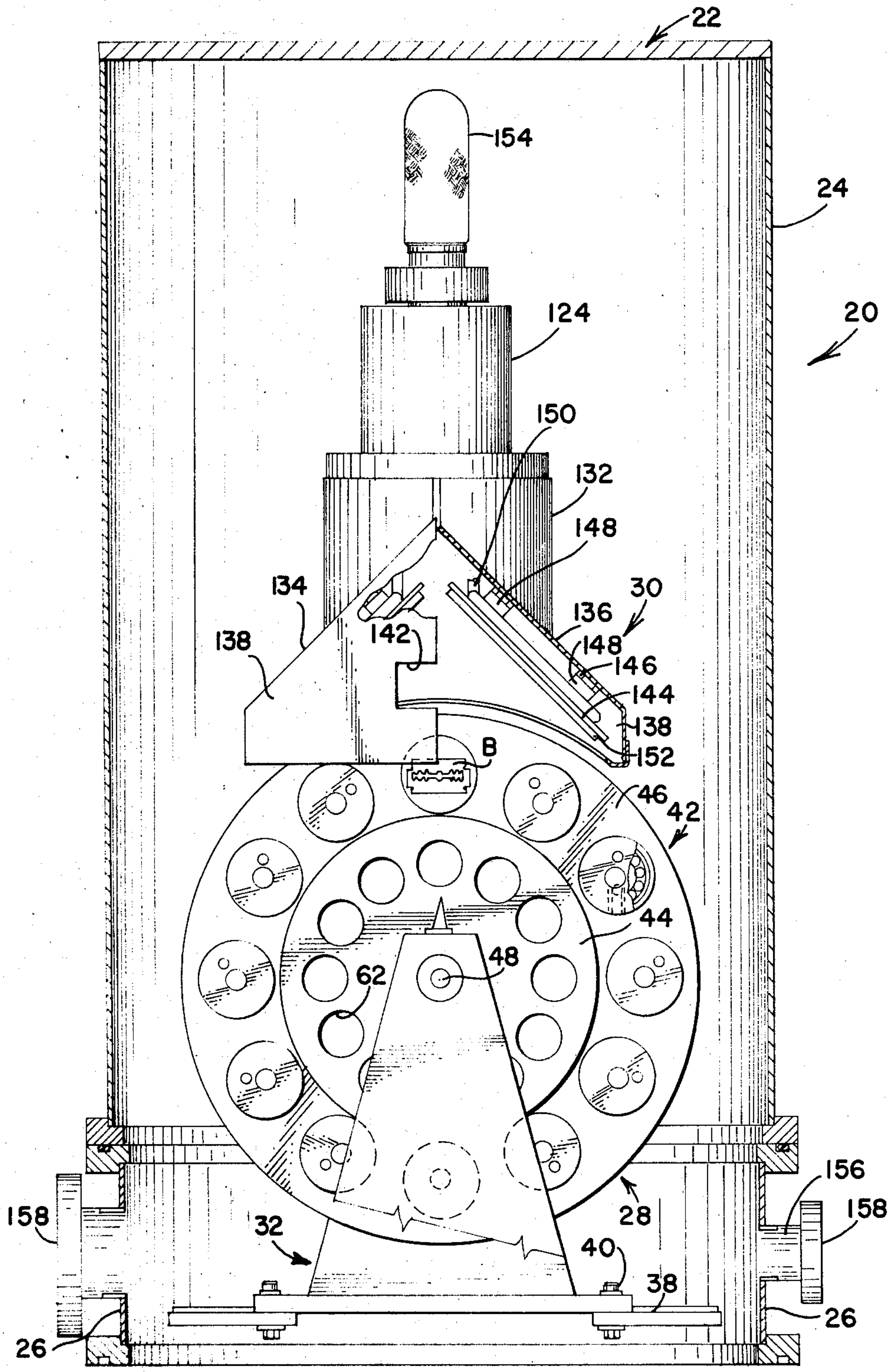


FIG. 1

INVENTOR
GEORGE C. LANE
BY Greist, Lockwood, Greenawalt & Dewey
ATT'YS.

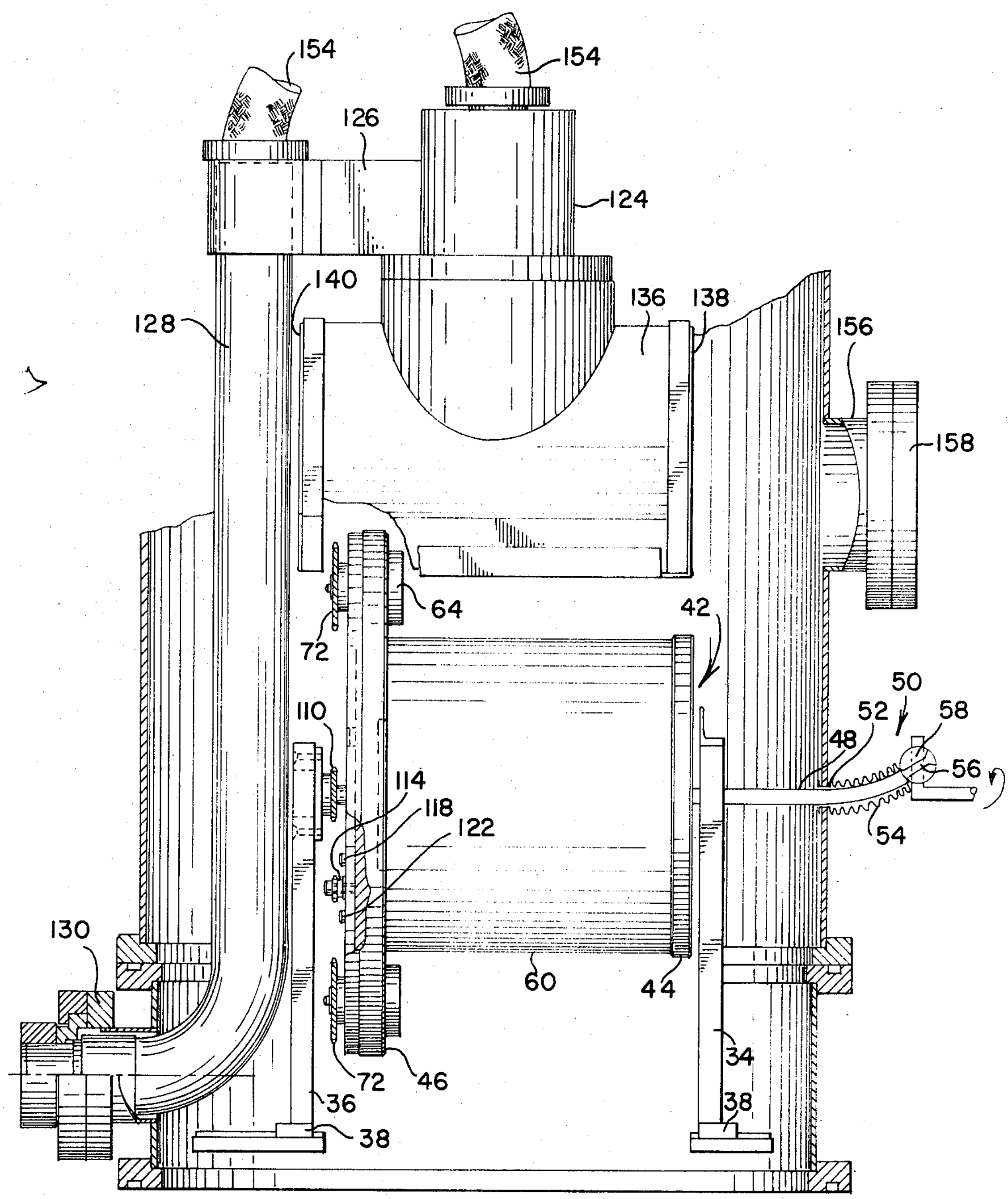


FIG. 2

INVENTOR
GEORGE C. LANE
BY Greist, Lockwood, Greenawalt & Dewey
ATT'YS.

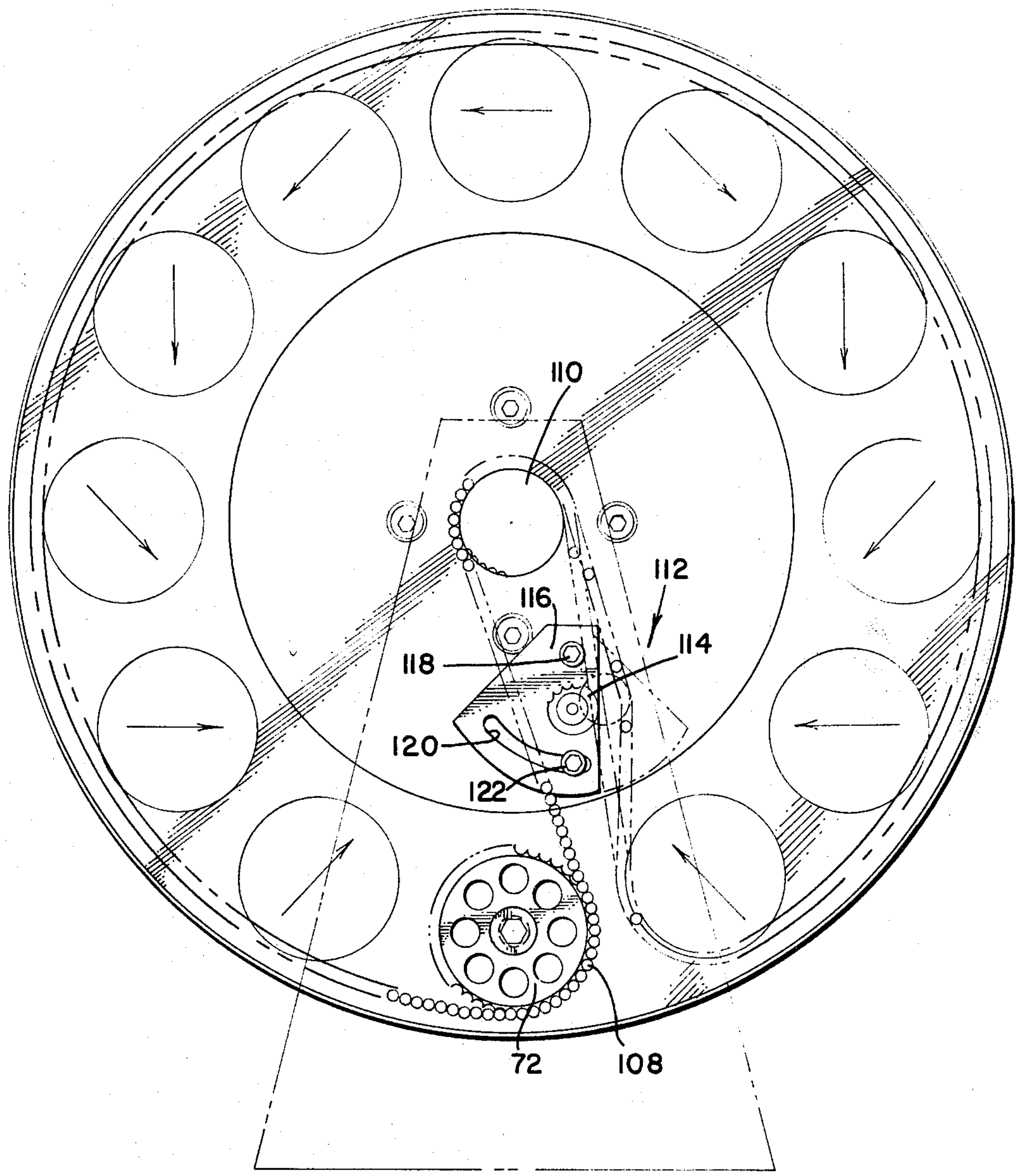


FIG. 3

INVENTOR
GEORGE C. LANE
BY Greist Lockwood Greenawalt & Dewey
ATT'YS.

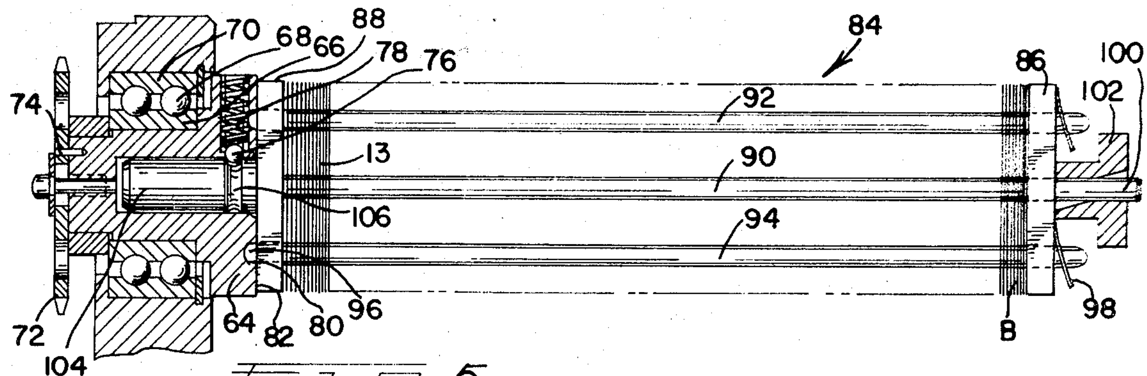


FIG-5

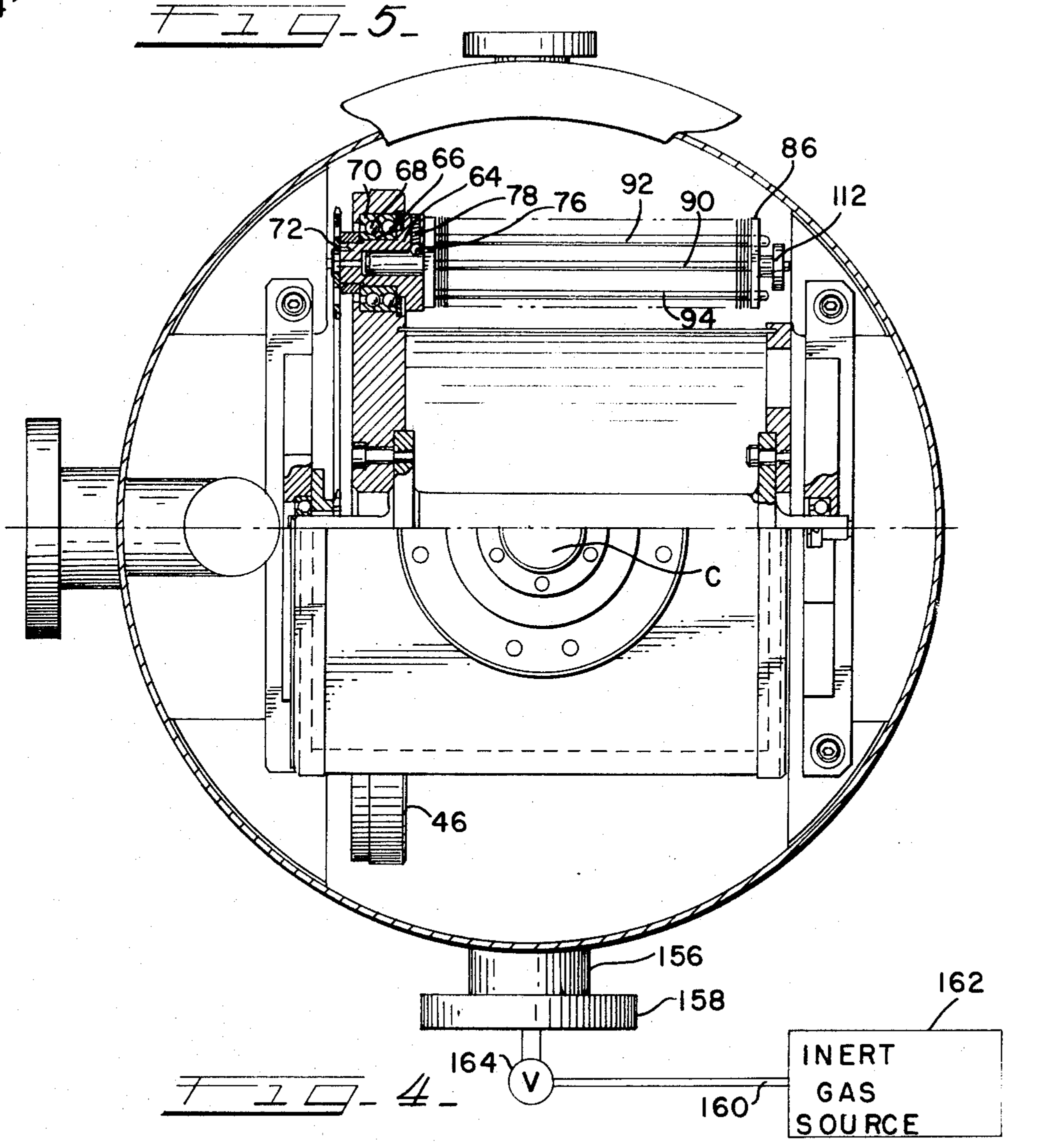


FIG-4

INVENTOR
GEORGE C. LANE
BY Trask, Godwood, Greenawalt & Dewey
ATT'YS.

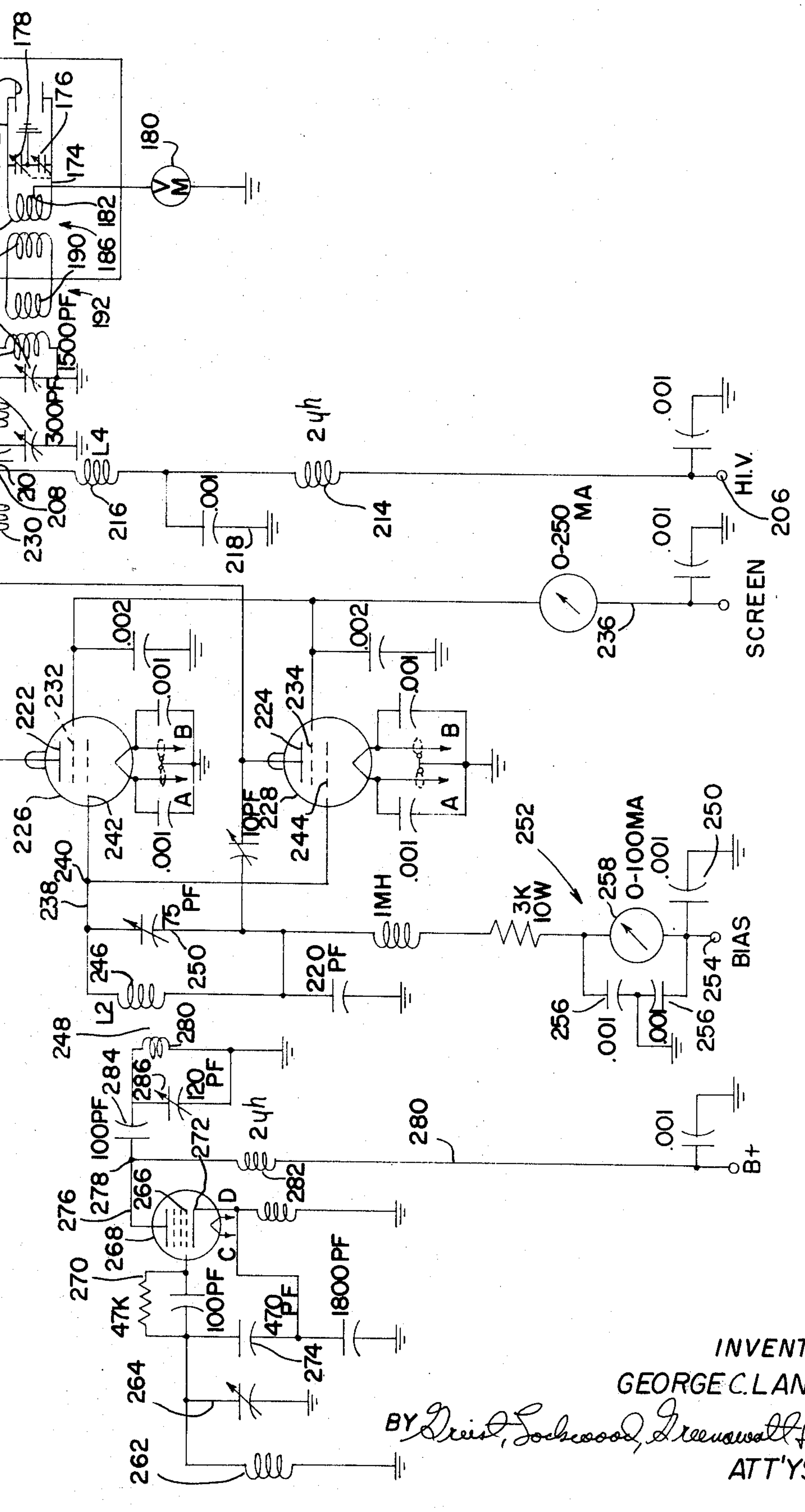


FIG. 6

INVENTOR
GEORGE C. LANE
BY Greist, Lockwood, Greenawalt & Dewey
ATT'YS.

FIG. 7

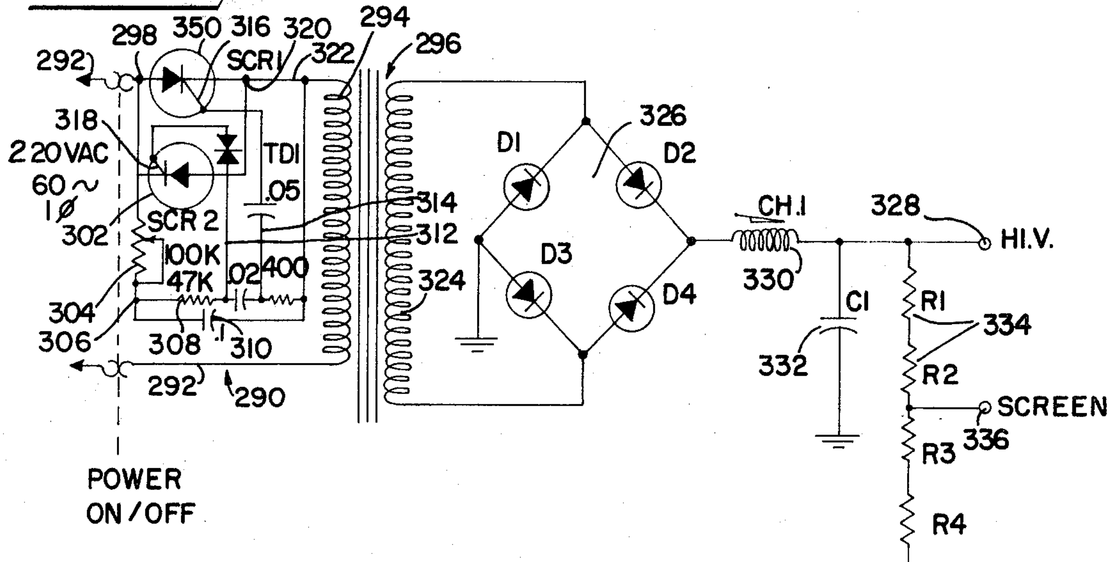
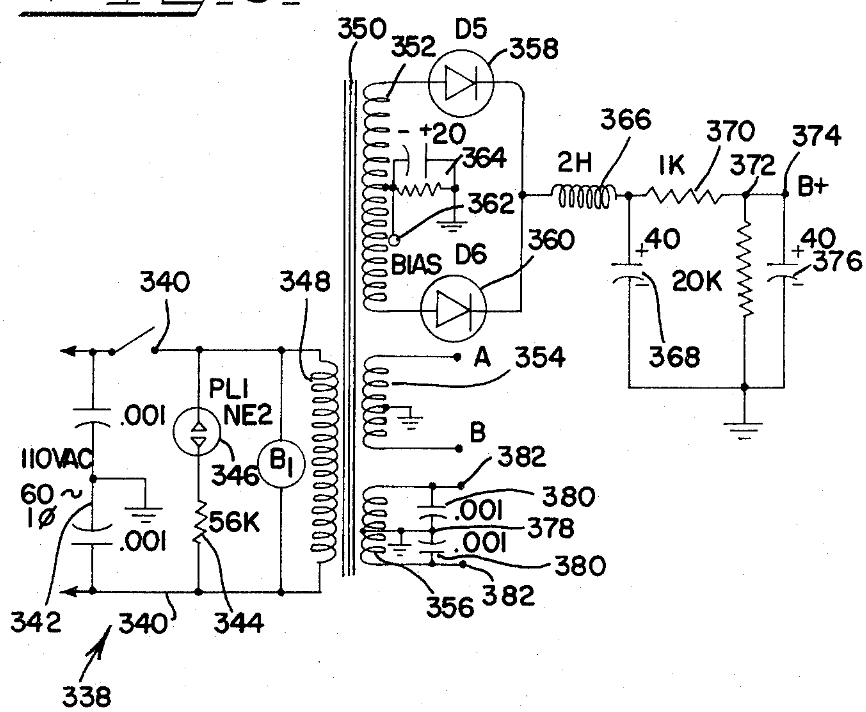


FIG. 8



INVENTOR
GEORGE C. LANE

BY Greist, Lockwood, Greenawalt, Dewey
ATT'YS.

METHOD OF APPLYING A COATING

BACKGROUND OF THE INVENTION

1. Field of The Invention

Generally, the present invention relates to a novel method and apparatus for surface coating of articles. More particularly, the field of the invention is that of metal substrate coating by a process analogous to metal transfer by so-called cathodic sputtering. In this process, the principal elements are an article or substrate to be coated, a coating material, a target plate for holding the coating material, electrode plates for causing gas plasma particles to strike the target to release the coating material, and means to control the deposition of the coating and means for carrying the article to be coated and for exposing the desired portions thereof to the sputtered coating.

The principal differences between the instant method and true cathodic sputtering are that the sputtered material need not be metallic, it is not a part of the cathode, and the process is of greatly improved efficiency in regard to rate and accuracy of deposition, operating temperature and in many other respects which are referred to further herein.

The method of the invention is desirably carried out by placing the electrode plates in a very high vacuum to form a "peak" or apex, with the upper edges thereof adjacent each other, and the lower edges more widely spaced apart and with an opening therebetween at the lower edges, placing the target plates immediately adjacent the inner surface of the electrode plates, impressing a very high-frequency alternating current on the plates, causing electron flow therebetween and development of a high charge thereon, and "leaking" argon or like gas into the interelectrode space. Thereupon, the electrons bombard the argon, ionizing it, and the plasma particles thus produced are attracted to the target plates by the space charge on the electrode plate. The plasma particles strike the target with such momentum that atoms or molecules from the target are "sputtered" from the target, whence, they are attracted to the article or substrate, which is suitably biased with regard to the electrode and target plates. Another aspect of the invention relates to the provisions of a mechanism for holding the desired articles or substrate, in this case, a plurality of razor blades, so that they may be passed in a controlled manner beneath the target plates containing the coating material. This mechanism may be generally described as a drum which is adapted to support a plurality of hubs which in turn support carrier means on which razor blades are removably mounted for coating. The drum and hubs are arranged, by means of an epicyclic gear or chain mechanism, so that they rotate in a desired time relation about two axes so as to expose the desired surfaces thereof to the opening beneath the target plates at particular angles to present those portions of the blade it is desired to coat to the target plates.

2. Description of The Prior Art

In general, the prior art methods of coating particular substrates with various materials, particularly covering substrates with thin metallic films has been accomplished by vacuum deposition of a thin film, generally by methods classified as evaporation, according to the following generally known methods.

A first method was an ordinary evaporation of a metal coating from a hot filament, wherein the filament was heated and the metal attached thereto was merely evaporated in the vacuum away from the filament along relatively straight lines in all directions, coating whatever object lay in their path. For example, in the art of electron microscopy, it is known to "shadow" a substrate by evaporating gold or other low boiling point metal, onto a specimen in order to create solid phase or permanent "shadows" which would be easily visible under a microscope.

An improvement in the ordinary evaporation method was the so-called electron beam deposition whereby the coating material was held in one location and an electron beam was directed at the coating material, the beam being formed and maintained by the application of a magnetic field to an electron source. A heated filament was used in this method.

Another known method is so-called diode sputtering, wherein high-energy electrons strike and ionize atoms of an inert gas as argon, and the ionized particles or plasma thus formed strike a target containing the coating. The target surface sputters off atoms which are attracted to an anode which contains the substrate. A method such as this is considerable improvement over several known methods, but the relatively large amount of ionized gas creates an arc effect and gives off considerable heat, even though this method has the advantages somewhat greater uniformity and good adhesion of the material to the substrate. Another, more modern method, is so-called triode sputtering, wherein the substrate is rendered positive, and electrons from a hot cathode are directed at the target, following which coating atoms are sputtered to the substrate which was desired to be coated. Although this method of coating possesses a number of advantages, it is in some cases not commercially desirable for coating many types of substrates, especially such as razor blades; since although this method uses less argon than other methods, and a longer mean free path is made possible for improved efficiency, this method is best suited for transferring only metals and alloys thereof, and still relies for its source of energy on a hot wire cathode, which may introduce ionic contaminants of tungsten, for example. In addition, the coated surface requires finish grinding after plating.

All of the foregoing known methods of deposition of thin films have been considered and although useful, they are not considered perfected for coating products having extremely fine cutting edges. Some of the purposes for which such coating is desired will now be discussed.

It has always been desired, in the razor blade art, to form a very sharp blade edge suitable for shaving, and to have that edge combine the advantages of corrosion resistance and longevity, as well as presenting a smooth and lubricous surface to the face of a shaver. Thus, it is desired to have a relatively corrosion-resistant blade having an extremely sharp surface and having the blade made from an extremely hard or tough material which would resist dulling. Thus, an ideal razor blade would combine the advantages of a long life in use as well as long shelf life, combined with an extremely sharp cutting edge and maximum smoothness for purposes of shaving comfort.

In the razor blade art, it is well known in the interest of shaving comfort, to coat a portion of the blade adjacent the cutting edge with a lubricous plastic, such as a fluorocarbon polymer, for example, polytetrafluoroethylene ("Teflon") or a polymer such as polyethylene, or the like. Likewise, in the last several years, razor blades made from more corrosion-resistant and tougher materials than those previously used have come into common use and have been accepted on a large scale commercially. Thus, the use of stainless steel for making razor blades is now quite common. However, it is likewise known that stainless steel is not the perfect material for making an ideal razor blade, but one which at present, best combines the advantages of acceptable competitive cost easy processability, corrosion resistance and durability of the shaving edge imparted thereto. However, even in spite of the great success of the stainless steel blade, there has been a demand in the razor blade art for a razor blade which would harmonize, at reasonable cost, the seemingly contradictory requirements of using a very hard, tough metal substrate for securing a long wearing blade edge, and using metals, which although sufficiently hard and tough to last for a long time, may nonetheless be readily ground to an extremely fine sharp edge, free from brittleness and microscopically jagged edges or voids in the sharpened surface.

Thus, a greatly improved razor blade would be one in which the blade could be manufactured from conventional materials, such as ordinary steel or stainless steel, and could then be given a very fine smooth metal surface coating, which would not require further finishing of the coating metal to impart these characteristics to the edge. However, since no known materials combine these advantages, a great deal of effort has been placed on developing methods and apparatus for coating blade edges of existing type razor blades. However, metal coating already sharpened blade edges by conventional methods has always resulted in an edge which requires further finishing, and the application of a hard coating, such as chromium, has resulted in a blade which was very brittle near the edge portions, and which was very difficult to grind down or polish to the desired degree of smoothness, especially at a reasonable cost.

Thus, there has been a great demand for a simple and economical method of placing a fine, hard, extremely smooth coating on a finished razor blade edge portion which would not require further treatment, but which would impart to such a blade edge the desirable characteristics of smoothness and hardness as well as corrosion resistance.

The invention of the applicant, namely the method of coating the blade edge by means of radiofrequency-induced plasma sputtering, and the development of an apparatus for carrying out this method, accomplished its objects, namely the provision of a method and apparatus for improved surface coating of razor blades and like substrates.

SUMMARY OF THE INVENTION

In view of the shortcomings of prior art methods and apparatus for coating razor blades, it is an object of the invention to provide an improved method and apparatus for placing a very thin, very fine coating, either organic or inorganic, on a sharpened metal surface after sharpening such a surface, to provide an improved blade or the like.

A further object of the present invention is to provide a method of coating a desired substrate with a desired coating material at low temperatures and at a reasonable cost, and to attain an extremely uniform coating which needs no further treatment to present a sharp cutting edge to the user.

Another object is to provide an apparatus for carrying out radiofrequency-induced plasma sputtering of a metal, metal oxide or other metal compounds or nonmetal coating material onto a razor blade.

Still another object of the invention is to provide a coating apparatus which is simple and compact to facilitate ready inclusion and use thereof in a high-vacuum chamber.

Another object is to produce a razor blade or like article with a sharp cutting edge which is suitable, after being treated as described herein, to be further processed as by coating with a polymer, without the need for additional intermediate preparation steps.

The present invention achieves its objects and overcomes the disadvantages of the prior art, by providing a method which includes the steps of providing a sputtering module which includes two flat electrode plates arranged to form a peak at one end thereof and an opening opposite the peak, placing target plates containing the coating material in front of the electrode plates, providing carrier means for supporting a plurality of articles to be coated, drawing a very high vacuum in the area surrounding the sputtering module and the carrier means, impressing a radiofrequency current across the electrode plates and electronically biasing the carrier means with respect to the electrode plates, "leaking" an inert gas into the region between the plates and passing the articles to be coated across the opening between the peaked plates so that electron bombardment of the gas ionizes the gas, the ions strike the target plates, sputtering the surface material therefrom, and the articles are uniformly coated by the sputtered material.

The method is advantageously performed by an apparatus which includes a drum or like means for carrying a plurality of articles holders past the sputtering module, and exposing a desired portion of the blades or other articles held on the carrier to the opening in the sputtering module in a timed relation so as to obtain a coating of desired uniformity, thickness and adhesion to the article. A preferred embodiment includes a drum holding a plurality of rotating hubs, and an epicyclic drive mechanism for rotating each of the articles carriers into a desired location as each hub unit passes the sputtering module, by utilizing relative rotation of the drum and hub assemblies.

Other and further objects and advantages of the present invention, including the manner of attainment thereof, will become more apparent when considered in conjunction with a description of the preferred embodiments of the invention described further herein and shown in the drawings, in which corresponding reference characters denote like parts throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a front view, partly in elevation and partly in section, showing the coating apparatus of the present invention;

FIG. **2** is a side view, partly in section and partly in elevation, and with portions broken away, showing the coating apparatus of the present invention;

FIG. **3** is a rear view, partly schematic, showing a portion of the coating apparatus of the present invention;

FIG. **4** is a top view, partly in plan and partly in section, showing the coating unit of the present invention;

FIG. **5** is an enlarged sectional view of the blade carrier unit shown in FIG. **4**.

FIG. **6** is a schematic view of a combination radiofrequency generator and impedance-matching network unit which may be used with the present invention;

FIG. **7** is a schematic drawing of a power supply unit for powering certain components of the combination unit shown in FIG. **6**;

FIG. **8** is a schematic drawing of a power supply unit for energizing other portions of the unit shown in FIG. **6**.

Referring now to the drawings in greater detail, FIG. **1** shows an outer vacuum chamber **20** including a top wall portion **22**, sidewall portions **24** and a base portion **26**, all of said portions cooperating for to form a chamber **20** which is capable of maintaining an extremely high vacuum therein, such as will be discussed in greater detail presently. The chamber **20** is shown as being made from metal, but it is understood that it may be made of glass or other light material known in the high vacuum art as being suitable for making such chambers. In the event glass were used, the shape of the chamber so would be that of a bell jar. If a frangible material, such as glass is used, an implosion shield (not shown) may be fitted, as is well known in the high vacuum art.

Contained inside the vacuum chamber **20** are the two principal components of the coating apparatus of the present invention, namely the carrying means **28** for supporting a number of razor blades or like articles to be coated, and a sputtering module **30**, in which is disposed the coating material which is to be placed onto the blades or other articles carried by the carrying means **28**.

Referring now to the carrying means, FIGS. **1** and **2** show that the means **28** includes a stand assembly **32** which contains a front leg member **34** and a rear leg member **36**, each of which includes feet **38** which are adapted to be fastened to a portion of the base **26** of the vacuum chamber by fastening means in the form of cap screws **40** or the like. Mounted on the stand **32** is a drum assembly **42** which comprises a front plates **44**, a rear plate **46**, a central axle shaft **48**, and drive means in the form of a crank unit **50** or the like.

In this embodiment, O-ring or like airtight seal means **52** are provided for attaching an inner end portion of the bellows **54** to the sidewall **24** of the housing chamber **20**. The bellows **54** includes a cylindrical extension portion **56** thereon, so that, as is shown in FIG. **2**, rotation of the shaft **48** and the drum **42** mounted thereon maybe accomplished without the need for a seal which contacts rotary parts, as long as the bellows **54** is sufficiently flexible to allow the knob **58** or other means mounted on the end of the shaft **48** to rotate and describe a circle about the axis of the shaft **48**. Referring again to the carrier 28, it may be seen that a cylindrical shell 60 connects the front and rear plates 44, 46 of the drum 42, and that a plurality openings 62 are provided so that the interior of the drum assembly 42 will be rapidly and completely evacuated when a vacuum is drawn on the vacuum chamber 20.

Referring now to FIGS. 4 and 5, it can be seen that the razor wall 46 of the drum 42 is adapted to carry a series of relatively rotatable hubs 64, and that these hubs 64 are carried by inner bearing races 66 on which balls 68 rotate, inside outer races 70. FIGS. 4 and 5 also show that the hubs 64 contain drive means in the form of chain sprockets 72 disposed on the outer portions thereof, and that the sprockets 72 are fastened as by keys 74 to the body of the hub 64. In addition each hub contains locking means in form of a ball 76 driven by a spring 78 exerting an inwardly directed force thereon, as well as a plurality of notches 80 in the inwardly directed faces 82 of the hub 64.

Referring again particularly to FIGS. 4 and 5, it will be seen that each hub 64 is adapted to receive blade carrying means in the form of a bayonet unit 84, which will be now described.

The blade carrying means or bayonet unit 84 comprises a front locking bar 86, a rear locking body 88, joined together by a center guide member 90, and on either side by left-hand and right-hand guide members 92, 94. Each of the guide members 92, 94 has a stub extension 96 adapted to be received in the recesses 80 in the front face 82 of the hubs 64, as previously set forth.

The front locking bar 86 is removably attached to the guide members 90, 92, 94, and in use, a plurality of blades B or other articles to be coated are placed on the guide members 90, 92, 94 and the front locking member 86 is then placed on the end of the members, and pushed finger tight to compress the blades B against each other into a relatively tightly abutting relationship. Locking springs clips 98 are provided for holding the bar 86 in place. An extension 100 of the center guide member 90 is provided for receiving handle means in the form of a knob 102 thereover so that munipulation of the bayonet 84 is facilitated. Extending outwardly from the rear locking bar 88, is a central support means in the form of a nose unit 104 having an annular circumferential groove 106 therein, whereby the locking ball 76, under the influence of the spring 78 may be urged into the groove 106, holding the nose 104 and the blade carrying means 84 associated therewith in the desired locked relation with the hub unit 64. The locking ball 76 and spring tension are desirably adjusted so that a moderate hand pull will remove the blade carrying means 84, but also so that the bayonets 84 will remain locked in position as shown in FIG. 5 unless pulled outwardly therefrom.

The diameter of the nose 104 is such that it will fit relatively snugly into the hub assembly 64 so that the entire bayonet 84 may be cantilevered outwardly of the hub 64. It is preferred that the knob 102 is integrally formed with, and fastened to, the front locking bar 86 so that the two may be removed and replaced or munipulated as a unit. It is also to be noted that the provision of the key 74 insures that the sprocket or the like drive means 72 will rotate with the hub 64, for reasons which will appear more fully herein.

Referring now to FIG. 3, it may be seen that, whereas each hub 64 carries an associated individual drive means 72 therewith, that a chain unit 108 is provided which engages the radially outermost edges of each of the plurality of sprockets 72, and, in between one pair of gears 72, the chain 108 extends inwardly toward the center of the drum member where it is trained around a stationary sprocket 110, which is held fixed in relation to the stand 32. A tension control means 112 is provided in the form of an idler gear 114 which is mounted on a pivoted plate 116 which pivots about a point in the form of a cap screw 118, through the arc permitted by the cutout 120. When the desired position of the idler gear 114 is reached, the locking screw 122 is tightened and the idler is held in a position placing the desired amount of tension on the chain 108.

In a preferred embodiment, it is desired to align the blade carrying means or bayonet units 84 so that a blade thereon will present a cutting edge thereof parallel with the top surface of the drum and directly under the sputtering module 30, and, upon rotation of the drum member through one cycle, will present the opposite face thereof to the opening beneath the sputtering module 30. Therefore, it is preferred that the stationary sprocket 110 contains a fixed number of teeth, say for example, 24, and that each outer or planetary gear 72 will contain just twice the number of teeth possessed by the stationary gear or sprocket 110, that is, 48 teeth in the example just referred to. In this manner, when each individual carrying means or bayonet 84 is presented to the opening in the sputtering module 30, alternate tope and bottom faces of blades carried thereon are presented in succession. Although it is not strictly necessary, in accordance with the present invention, to use a chain driving means, the use of a chain is simpler and less expensive, and provides for a generally more desirable layout than other driving means, such as gears or the like, and is more economical.

Thus it will be seen that the carrying means for the blades or the other articles to receive the desired coating generally comprises a drum means held on a suitable stand and constructed and arranged so that rotation of the drum itself serves to rotate the bayonet members held on the hubs so that alternate tops and bottoms, for example, of the articles held are presented to the sputtering module as described above.

Referring now to a second principal component of the invention, sputtering module 30 is supported in place by a ground shield cylinder 124 which is held by support means in the form of an arm 126 fixedly fastened to a rigid vertically disposed conduit column 128, which in turn is fastened to a frame assembly 130 in the base 26 of the housing chamber 20. Immediately beneath the ground shield cylinder 124 is a holder unit 132 which supports left-hand and right-hand ground shield members 134, 136, to which are attached end walls 138, 140, the front end wall having a viewing window 142 disposed therein. The inside of the sputtering module 30 contains identical left- and right-hand electrode plates 144, which are supported by fasteners 146 holding insulators 148 to insulate the electrode plates 144 from contact with the ground shields 134, 136. Current is supplied to the electrode plates 144 by means of lead means 150. In the preferred construction, the lead means 150 are in the form of a hollow copper tubes which are brazed, soldered, or otherwise securely electrically and mechanically fastened to the electrode plates 144. The copper tubes 150 serve as combination electric lead and coolant conduits, inasmuch as each hollow copper tube is adapted to circulate water on the inside thereof, and to carry the radiofrequency charges to the plates 144, around the exterior of the tubes or leads 150. Target plates 152 are disposed on the inner edges respectively of the electrode plates 144, and may be fastened thereto by any suitable means, preferably means which facilitate removal and replacement of the target plates 152, such as spring clips or the like, illustration of which is omitted for the purpose of clarity.

Referring now particularly to FIG. 1, it will be understood that only the right-hand electrode plate 144 and carrying means therefor, as well as the right-hand target plate 152 are shown, but it will be further understood that an identical left-hand plate is provided in an exactly corresponding location on the other side of the module 30, that is, supported in place by the left-hand ground shield 134. Together, the two plates 144, when disposed within the ground shields 134, 136, as shown, form what is referred to herein as a "peak," or a "plasma peak" which has such geometry in order to facilitate the flow of electrons between the two plates, as well for purposes of leaving an opening therebeneath for the passage of the articles to be coated. It is not strictly necessary, in accordance with the present invention that the "peak" be of the exact configuration shown, or that the opening disposed at the bottom thereof, but such construction has proved most efficient, and accordingly is preferred in keeping with the present invention.

Referring again to the FIG. 1, it will be noted that a large sheated cable means 154 or the like is shown surmounting the ground shield cylinder 124, and this sheath 154 carries a coaxial cable means inside thereof, ("C." Fig. 4), from which the leads 150 extend to the electrode plates 144. The sheated or armored cable 154 then extends downwardly through the column 128 and thence outwardly of the vacuum chamber 20 to the impedance matching network and radiofrequency unit which will be described further herein.

Referred now to FIG. 2, it will be seen that the locations of an oil diffusion pump and a cold trap are schematically represented. Inasmuch as the present invention is essentially concerned with the deposition of materials in a very high vacuum environment, the diffusion pump and cold trap are shown to be present. However, it is well known to those skilled in the art that the conventional method of evacuating a bell jar or like vacuum chamber 20 is by means of an ordinary mechanical or so-called "roughing" pump, following which an oil diffusion pump or the like is used, which takes the advantage of adsorption of nitrogen, oxygen and like molecules by oil vapors, which may then be easily trapped and excluded by the diffusion pump, backed by a suitable "backing type" mechanical pump, also well known in the art.

The cold trap which is schematically shown normally consists of a ring surrounding the neck or junction between the diffusion pump and to the bell jar to prevent backflow of oil into the bell jar. The cold trap is maintained at an extremely low temperature by circulation therethrough of liquid nitrogen or other coolant. The operation of such "roughing" pumps, oil diffusion pumps and cold trap units are well known and conventional in the art of vacuum deposition and do not form any essential novel part of the present invention. All that is required is a diffusion pump system or other like means which are capable of attaining vacuums of the desired order inside the chambers which are referred to in greater detail below.

Likewise, referring to FIGS. 1 and 4, there are shown a plurality of outlets 156 or the like, having covers or plugs 158 therein which are adapted to be vacuum sealed, but which are placed in the base 26 or the like of the vacuum chamber 20 for purposes of access to the interior of the chamber 20. In this manner, it is easy to introduce members such as the conduit 128 shown in FIG. 2, or to provided valve means for introducing the gases referred to in detail below.

Thus, FIG. 4 schematically shows a connector 160 leading to an inert gas source 162, and shows that regulator and needle valve means 164 may be provided to control the flow of gas from the source 162 to the interior of the vacuum chamber 20. These features are used with the present invention, but their particular structure forms no essential part of the invention, and thus no details of these units are shown.

Referring now to FIG. 6, there is shown a combination oscillator, amplifier, and impedance matching network unit 166.

FIG. 7 shows a power supply unit for some of the components of the combination unit 166, and FIG. 8 shows a power supply unit for some of the other components thereof.

Referring now to FIG. 6, and to the combination unit 166, there is shown a "matching box" or impedance matching network 170 which includes leads 172 and 174, each of which terminates in plates 144. These are the plates across the radiofrequency voltage referred to elsewhere herein is impressed, that is, the electrode plates in the vacuum chamber. Tuning of the plates 144 is accomplished by adjusting the variable capacitors 176, 178 which extend across the leads 172, 174. A voltmeter unit 180 is center tapped at 182 to the secondary 184 of the matching box transformer 186. The primary 188 of the transformer 186 is connected to the secondary 190 of the output transformer 192. The primary of this transformer, in combination with a variable capacitor 196, forms an output tuned circuit which is connected through a coil 198 and a capacitor 200 to the output circuit of the amplifier portion 202 of the combination unit 166. A grounded capacitor 204 is connected between the coil 198 and the capacitor 200.

A high-voltage connector 206 carries high voltage to a junction 208 between the output line 210 and a lead line 212, through two coils 214, 216, between which is disposed a filter capacitor 218. From the junction 220, the lead line 212 is connected to the plates 222, 224, respectively of the power tubes 226, 228. The plate current flowing to the junction 220 and in line 212 passes through a coil 230 before being fed to the output transformer 192. Since power tubes 226, 228 are connected in parallel, it will be noted that screen grids 232, 234, are connected to a common screen grid input line 236.

From this drawing it also may be seen that the control grids 242, 244 of the power tubes are connected in parallel at the junction 240. The voltage at line 238 consists of DC bias and RF drive. The bias is supplied at pf. connection 254 and is fed through an assembly 252 including a milliammeter 258, the 3 K 10 W. resistor, the 1 Mh. choke and the secondary 246 of the transformer 248 (L2). The RF grid drive is developed across the secondary 246 of transformer 248, tuned to resonance by the capacitor 250. The 10 pf. variable capacitor is tuned to neutralize the plate to grid capacitance of the tubes 226, 228. It accomplished this by providing a negative feedback path from the plate to grid circuit, thus eliminating self-oscillation of the output tubes. The 270 pf. capacitor and 1 Mh. choke are part of the neutralization circuit. The 3 K resistor is a grid leak resistor, providing a minimum bias level. The capacitors 256 are RF bypass capacitors.

Referring now to the oscillator portion 260 of the unit 166, it is shown that the circuit is a so-called Colpitts-type oscillator. The coil 262 and capacitor 264 are the major frequency determining components. The capacitor network 274 attached to the grid control 266 of the tube 268 for oscillation, the level of which is determined by their ratio. The choke coil connected to the cathode 272 provides the feedback voltage for the capacitive voltage divider 274. The resistor 270 is a grid leak bias resistor. The capacitor in parallel with it stabilizes the bias. The oscillator output is developed across the plate choke 282, capacitively coupled by capacitor 284 to the tuned primary 288 of the transformer 248 (L2). The primary is tuned to resonance by capacitor 286. The plate lead 276 is joined at 278 to the line 280, which connects to the B+ voltage source.

Thus, the output of the oscillator tube 268 is inductively coupled to the amplifier unit 202, and from the amplifier, the signal is fed to the matching box and supplied to the plates 144. As stated above, a preferred frequency of operation is about 13 megacycles per second, at a net power rating of about 600 watts or more.

Referring now to FIG. 7, there is shown a combination voltage control and rectifier unit for supplying regular power to the radiofrequency amplifier just described. This voltage control and rectifier unit 290 comprises leads 292 for attachment to a 220-volt, 60-cycle single-phase alternating-current source. One lead 292 is directly connected to a primary winding 294 of a transformer 296, and the other lead is split at junction 298 between connections to one terminal of a semiconductor controlled rectifier (SCR) 300 biased in one direction, and the other connection is joined to an oppositely biased SCR 302, the two SCR's being reverse parallel wired. A variable resistor voltage control unit 304 is connected in series between the terminal of the second SCR 302 and a junction 306, to which are connected a resistance-capacitance-resistance circuit 308 and a capacitor 310 in parallel. Take off lines 312 and 314 are fed respectively from the resistance-capacitance-resistance circuit 308 to the gates 316, 318 of the SCR's 300, 302. At junction 320, the output from the cathode of SCR 302 and from the anode of SCR 300 are joined, and lead 322 connects this junction 320 to the primary 294 of the transformer 296.

The secondary 324 of transformer 296 has the ends thereof respectively connected to a conventional diode-rectifying bridge 326, of which one lead is grounded and the other fed to a high-voltage source 328 through a choking coil 330. A fixed capacitor 332 cooperates with the choke 330 to stabilize or smooth the output of the rectifying bridge **326**. Direct current dropping resistors **334** are provided so that a lower voltage may be fed from terminal **336** to the screen grids of amplifier tubes **226**, **228**.

Referring now to FIG. **8**, there is shown a power supply adapted to furnish B+ voltage to certain elements of the amplifier, oscillator and matching box unit **166**, and to furnish heater current for tube filaments. This power supply **338** includes leads **340** for connection to a 110-volt, 60-cycle, single-phase alternating-current source, and these leads have a radiofrequency filter system **342** disposed across them. A resistor **344** and neon tube **346** are also wired parallel to the leads **340**, which connect to either end of a transformer primary **348**, which is coupled through a core **350** to three separate secondaries, a B+ secondary **352**, another secondary **354** having outlet leads marked "A" and "B," and a third secondary **356** having outlet leads marked "C" and "D."

The B+ secondary **352** has rectifier diodes **358**, **360** attached to either end thereof, and a bias connector **362** as well as a center tapped and grounded parallel resistance-capacitance circuit **364** connected thereto. The output from the rectifying diodes **358**, **360** is fed through choking coil **366**, and is further stabilized or evened out by reason of the capacitor **368**. The direct current from the B+ source is then fed through resistor **370** to a grounded resistance connector **372** and from there to a B+ outlet **374**, which is also grounded through a capacitor **376**.

In the above schematic, and in FIGS. **6**, **7** and **8** of the drawings, the abbreviations used have the following meanings. Where "K" used, is meant 1,000 of the unit concerned, i.e., 50 K applied to a resistor is 50,000 ohms, H is the henry and the henry, and the "mu" legend, when used with the "H" microhenries, as does the M when used with the "H." Unless otherwise indicated, capacitances are indicated in microfarads, i.e., 0.001 indicates 0.001 microfarads, whereas pf. is the abbreviation for picofarads, i.e., 10^{-12} farads. The "A," "B" and like letters indicate the connections between the outputs and inputs between circuits shown in the various figures.

The "A" and "B" secondary **354** is center tapped and grounded, and the low-voltage output therefrom is used to heat the filaments of the tubes **226**, **228**. Similarly, secondary **356** contains a center tapped connection **378** which is grounded and connected to two capacitors **380** disposed across the output lines **382** leading to the heating element for the oscillator tube **268**.

In keeping with the teachings of the present invention, a number of different products were made according to the processes set forth in detail below.

EXAMPLE I

The apparatus shown in FIGS. **1** to **4** was used with a bell jar **20** comprising the outer vacuum chamber. A plurality of razor blades were carefully cleaned, as by immersing them in, and evaporating therefrom, a solvent, such as trichloroethylene or other suitable solvent. The blades were placed on holding means, such as the bayonet unit shown at **84** in FIG. **5**.

A pair of target plates were prepared by taking two mild steel plates, placing a heavy chromium plating on one surface of each plate by a conventional electrolytic deposition method. The plating may be of any desired thickness. Thereafter, these plates were secured to the inside surfaces, respectively, of the electrode plates **144** in the position shown at **152** in FIG. **1**, for example.

Thereafter, a mechanical "roughing" pump was turned on, evacuating most of the air from the vacuum chamber **20** to a pressure of 100 microns approximately. By means of an oil diffusion pump and cold trap, the pressure inside the air chamber **20** was further evacuated until a pressure of 1×10^{-5} millimeters of mercury was attained.

Thereafter, by means of a needle valve or like so-called leak valve, such as that schematically indicated at **164** in FIG. **4**, argon gas was allowed to be introduced into the chamber **20** until pressure was raised to 3×10^{-3} millimeters of mercury (Torr).

Thereupon, the radiofrequency generating unit such as that shown in FIG. **6** was actuated, and a radiofrequency of 13.56 megacycles per second was impressed on the plates **144**, the matching network associated with the RF unit being adjusted or tuned so as to minimize the impedance mismatch caused by the lead of target plates **152**. Charging of the plates with the RF current immediately causes a plasma to produced between the plates. Thus, the electrons emitted by the plates **144** rush back and forth therebetween at a frequency of about 13,000,000 complete back and forth cycles per second and many of these electrons strike the atoms of argon gas disposed between the plates. Because of the argon atoms or other inert gas atoms, are very massive in relation to the mass of electrons, the argon atoms or molecules themselves are not substantially moved by the movement of the electrons or attracted by the charge which builds up on or closely surrounding the plates **144**. However, the high-frequency electrons bombarding the argon gas cause ionization thereof, and upon ionization each positive ion or argon is strongly attracted, by reason of the high negative charge, to one or the other of the plates **144**. This high space charge accelerates the argon atoms toward the electrode **144** with great energy. However, the ionized atoms strike the target material which is placed on the target plate **152** placed immediately in front of the electrode **144**. The momentum with which the ionized argon atom strikes the target plate may be sufficient to sputter one or more atoms or molecules off the target plate **152**.

When initial ionization takes place, the pressure is reduced by reducing the rate of addition of argon, to approximately 1.5×10^{-3} mm. of mercury. Thereupon, the RF energy input is raised to a value of 600 watts forward power.

A DC bias of 1,800 volts is built up between the RF system and the blade or article carrying means, this bias resulting from the negative space charge on the plates **144** in relation to the potential of the carriers **84**, which are fully insulated from the plates **144**. The bias occurs because of the intrinsic characteristics of the circuit, that is, the plates **144** take on, or appear to take on, a strong negative charge. While the particles which are sputtered from the target plate are in a neutral state, that is, they are not ionized, and therefore are not attracted to the substrate or article to be coated by reason of the bias between the plates **144** and the article carrier, a certain degree of bias is desirable to prevent positively charged argon or like ions from striking the articles, since this would result in "re-sputtering" either the substrate or the coating sought to be applied.

Thus, the bias between the plates and the carrier is desirable, but its value is not of critical importance to the invention.

Thereafter, the amount of forward power in the system is then adjusted by altering the amount of argon introduced into the system by a very minute adjustment. It is preferred that after arriving at a pressure of between 1 and 2×10^{-3} millimeters, and adjusting the impedance matching network, there will be about 500 to 600 watts forward power and about 100 watts or less of reflected power, leaving a net power input into the "plasma peak" or to the two plates and the area therebetween of about 500 to 600 watts, and preferably about 510 to 550 watts. Power levels of greater or lesser quantity will directly affect sputtering rate. Under these conditions, sputtering will proceed for a period of approximately 4 minutes, and a coating having a thickness of about 625 angstroms (A.) will be deposited upon a flat surface, and half that thickness, namely 264 angstroms, will be deposited on the edge portions of a razor blade, disposed with the razor edge portion thereof directed generally to the area between the plasma peak.

The razor blades coated by the process just set forth were shown to process an extremely fine, pore-free and uniform coating of chromium, rendering them resistant to rust and corrosion. Such blades, which possessed a very sharp or keen edge, also required no further honing or other treatment, and were ready for next process stage when removed from the vacuum chamber.

Although the exact reasons for the success of the sputtering apparatus and method of the present invention, are not entirely understood, it is believed that, because the coating material is liberated from the target plate in substantially atomic or molecular size particles, the adhesion thereof to the substrate or articles to be coated is not only very strong but, since the charges possessed by the coating material particles are the same and such charges tend to repel each other, the individual atoms each tend to seek out one particular location in the substrate and repel other atoms from that immediate area until the entire substrate is uniformly covered and thus attains a fine, even coating surface.

By "charges," as used in the preceding paragraph, referring to the charges on the particles of the coating material, it will be understood that these particles are not ionized, but merely have a slight electrostatic or like surface charge of an extremely small magnitude.

In fact, if a physical analogy might be made, the sputtered atoms or molecules act, upon contacting the substrate or article to be coated, somewhat as droplets of water when placed or spilled on hot frying pan or the like. Thus, in this analogy, the droplets of water would be compared to atoms having a surface charge, and the fine subdivision and rapid movement thereof is characteristic of the atoms striking the substrate. Thus, the atoms being surrounded by their own charge, much as the heated droplets of water are surrounded by a vapor phase of their own, tend not to coalesce in one location but to spread themselves about in a random manner. Thus, a razor blade like article coated according to the present invention is characterized by an extremely thin but very smooth coating, since the method apparently creates a coating in which the deposited or coating material is placed upon the substrate substantially literally one molecule at a time.

EXAMPLE 2

It is also well known, in the razor blade art to coat a portion of a razor blade in an area which is very close to the cutting edge with a polymer having lubricous characteristics, such as a polytetrafluoroethylene or like fluorine- or chlorine-containing polymers, or polyethylene, or other lubricous plastic material. However, prior methods have involved suspending the polymer in a solvent or the like and, after placing a liquid phase coating on the blade, evaporating the solvent and curing the polymer. However, as set forth below, the present method may be used for direct polymer coating of blades or the like. Initially, steel plates or blades **152** approximately 6 inches by 9 inches in size and about one-fourth of an inch in thickness where sprayed with a film of polytetrafluoroethylene and the coating thus sprayed was baked out or cured in a reducing atmosphere for 20 minutes at 700° degrees F.

It is preferred to perform this operation in a very high vacuum to avoid entrapping gases in the coating which could create a reaction with the polymer or other materials present in the chamber or interfere with the generation of the plasma.

These plates were clipped into position just inside and adjacent the plates **144** into the position shown at **152** in FIG. **1**.

Next, razor blades were cleaned as set forth above, in example 1, by immersing in a solvent or the like.

Next, the bell jar was evacuated by means of mechanical and diffusion pumps to a pressure of 1×10^{-5} millimeters of mercury. Thereupon, argon was introduced until the pressure attained a level of 3×10^{-3} millimeters of mercury, and a plasma was achieved at this pressure by impressing approximately 100 watts of RF energy across or into the peak defined by the plates **144**. Once ionization took place, that is, once the plasma was established, the argon pressure was reduced to an operating level of 1.5×10^{-3} millimeters of mercury.

Thereupon, the RF energy was increased to a net power of about 275 watts, that is, about 300 watts forward power and 25 watts reflected power. In this example, the bias between the grounded carrier unit **84** and the plates **144** was approximately 800 volts of self-biased DC. In this example, the process was continued for a period of approximately 5 minutes. Under these conditions, approximately 1,200 A. of a plastic material were deposited on an optical flat which was placed in the chamber **20** near the articles to be coated, and the coated articles contained a corresponding amount of plastic material, depending on their configuration that is, on the amount of surface and angle thereof presented to the plates **144**. A coating such as this may be deposited in any desired thickness, preferably, in this case about 200 to 2,000 A. in thickness.

Analysis of the films deposited by this method, by both infrared spectroscopy and nuclear magnetic C–F (NMR), showed that the deposited plastic was of different composition than that of the plastic which was placed on the plates **152**, differing in that some of the characteristic C–F (Carbon-fluorine) bands had disappeared, and in that the molecular weight of the coating material had been reduced by an order of some of two to five times. The resulting polymer deposited on the substrate or coated article was nevertheless a somewhat similar polymer, containing the same elements even though the exact crystal structure of the initial polymer has been considerably altered. Thus, this example demonstrates the use of the novel method for simultaneously depositing and altering or rearranging in a polymer in one step.

EXAMPLE 3

In this example, all the conditions were the same as those set forth in example 1; the coated material was chromium, a plurality of blades were placed on the bayonet or carrying unit **84**, and a plurality of these carrier units **84** were inserted into the hubs **64**. Thereafter, the sputtering process was carried out in accordance with the conditions of example 1, except that it was continued for a longer time, and the entire carrier unit **28** was revolved through two complete cycles, thus exposing the top and bottom edges of the plurality of razor blades held in each bayonet unit **84** to the plasma peak or sputtering module **30** for the same length of time and at the same angle as all the other blades. The process was timed so that a coating of approximately 100 up to about 200 to 300 A. of chromium was deposited on the edge portion of each razor blade. In this example, the argon was continually admitted during the process, maintaining the operating pressure set forth in the first example and the sputtering took place continuously until each bayonet unit had made two passes beneath the sputtering module **30**. The drum unit was revolved at a rate of one quarter of a revolution per minute and two complete cycles of rotation thus coated both edges of all blades in 8 minutes of operation. The coating thickness referred to herein and in example 1 are merely illustrative, since these coatings may be of any desired thickness.

EXAMPLE 4

In this case, a process similar to that set forth in example 1 was carried out, except that the deposited material, instead of being metallic chromium, was an alloy iron, nickel and chromium, one brand of which is known as "Nichrome." After carrying out the process according to the conditions set forth in example 1, it was discovered that the article contained a coating of the alloy which was placed on the target plates **152** in the same exact composition as the composition of the alloy on the plate. Thus, the method demonstrated its ability to transfer alloy from the target to the substrate without altering the composition of the alloy.

EXAMPLE 5

In this example, the condition were the same as those set forth in example 3, except that the coating material was the alloy of example 4.

EXAMPLE 6

In this example, conditions were the same as those in example 1 or 4, except an iron carbide material, having a very hard surface, was coated onto a razor blade by the same process.

EXAMPLE 7

A method such as that referred to in example 1 was carried out, with all conditions thereof remaining the same, except that during the time the argon was leaked into the bell jar, a small amount of oxygen was allowed to enter the jar. By allowing sufficient oxygen to enter the jar to react with the chromium, but not enough oxygen so as to substantially diminish the vacuum in the system or to interfere with the creation of the plasma, it was discovered that a coating of chromium oxide was able to be placed on the blades. Thus, this method demonstrates the ability of the method of the present invention simultaneously to carry out coating deposition and to allow a chemical reaction between the coating material and another product introduced into the vacuum chamber.

It is believed that, since the sputtered coating material is generally in a monoatomic or monomolecular form, the availability of individual atoms or molecules for reaction is great, and the probabilities of the desired reaction taking place are excellent. Thus, a principal advantage of this method is that it makes possible what is essentially a gas phase reaction at temperatures greatly below the vaporizing or sublimation temperatures of refractory materials, such as, for example, the types of metals referred to herein.

Those blades referred to in the preceding examples in which a metal or metal-containing compound was applied to the edge were suited to receive an additional coating of plastic, over the newly coated edge, either by a subsequent sputtering operation or by conventional methods.

As pointed out above, a principal advantage of this method is that no treatment subsequent to sputtering is required to prepare the coated article for use or for a subsequent coating operation. Particularly in the case of razor blades, this is a great advantage, since, in the past, two honing operations were required for a blade with a coated edge, and honing is an operation which adds considerably to the cost of a blade.

In all the embodiments described herein, the target plate means **152** was shown as being different from, or separate or separable from the electrode means **144**, but will be understood that the reason for this construction is not that such plates need be separate, but that constructing them separately is the preferred method of being able to coat them with the desired coating material, place them in position, and then remove them for recoating when indicated.

In the case of the metal coating material, once the target plate is attached to the electrode plate, the two plates **152**, **144**, electrically speaking, are the same as only one plate, that is, the charge on the target plate is of the same order and type as the charge on the electrode plate. In the case of the nonmetallic coating material, however, the plates tend to behave somewhat differently, since current will not flow through dielectric material in the same manner as it flows through metal. Still, the behavior of the system is the same as through the electrode plates **144** were coated with a dielectric material.

Thus, the target plates and the electrode plates are illustrated herein, and defined in the appended claims, as being separate entities, but it will be understood that the two could be integrally constructed, if this were desired.

Furthermore, the above-described method makes possible the application of films, whether metallic, inorganic, or organic, of thickness which are thinner than those previously achieved in the cutting edge and the razor blade art, for example.

As set forth in example 1, a razor blade prepared according to the present invention will have a coating, for example, of a thickness of 100 to 600 Angstroms, that is, between one and six one-hundredths of a micron. Thus, although it has been known to apply metal coatings, for example, by evaporation, in thickness of somewhat less than a micron, it is believed that it is not heretofore known to coat a blade with a thickness of metal of one to six one-hundredths of a micron.

It is believed that one reason that such a thin coating is satisfactory is that the sputtered molecules have such momentum, when sputtered from the target, that they are firmly held by the substrate, and, in addition, since no subsequent honing or stropping is required it is not necessary to add additional thicknesses of material, which would then merely be grounded away in a resharpening operations.

Likewise, coating the fluorocarbon, hydrocarbon, or other polymer over an ordinary carbon steel blade edge, over a stainless steel blade edge, or even over an edge coated with chromium according to the method of the present invention, or otherwise, is believed novel in that such coating may be applied with a thickness of as little as 200 Angstroms or less, or as large as 1,200 to 2,000 Angstroms or more. Such coating thicknesses are much smaller than those presently able to be achieved by other methods. In addition, blades having such thin coatings have not been heretofore known, since it has not been possible to apply such a thin coating in a reproducible manner.

Although the reason therefor is not clearly understood, it is known that coatings such as those described herein may be applied to the cutting edges of blades, as described, without joining the edges together. It is possible that, since the electrode plates are disposed at an angle relative to the faces which define the cutting edges of the blades or other instruments, that sputtered molecules do not ordinarily have a vertical trajectory, and thus do not tend to fly vertically into the "valleys" between blade edges, at least in substantial numbers compared to the number striking the faces near the cutting edges. At any rate, there has somewhat unexpectedly been no problem with blades sticking together; this is another advantage of the invention which facilitates treatment of large numbers of blades at low cost.

It will thus be seen that the present invention provides a novel apparatus, method and articles having novel advantages and characteristics, including those hereinbefore pointed out and others which are inherent in the invention.

Having completed a disclosure of my invention, in keeping with the patent statutes, so that one skilled in the art may practice the invention, I contemplate that certain variations may be made herein without departing from the spirit of the invention or the scope of the appended claims.

I claim:

1. A method of successively applying a coating of a first, metallic material and a coating of a second, organic plastic material to the faces and cutting edge portions of a plurality of individual cutting instruments, each of which include two honed relatively hard metal face portions with a narrow included angle therebetween, said faces meeting to define said cutting edge portion, said method comprising the steps of supporting said plurality of instruments on carrier means with said instruments having their sides abutting one another, and having said edges arranged in a common plane, disposing at least one electrode in the region of said instruments, positioning at least one target having said first material thereon in closely overlying relation to said at least one electrode, positioning said carrier means such that said edges are in an at least partially facing relation to said target, substantially evacuating the region surrounding said instruments, including the region surrounding said at least one electrode, impressing a radiofrequency alternating voltage gradient between said electrode and a reference point sufficient to cause significant electron flow in said evacuated region adjacent said electrode, introducing a minute amount of an inert gas into said evacuated area, whereby said flowing electrons ionize some of the molecules of said inert gas to form a plasma, and whereby the ions from said plasma strike said first material and sputter said first metallic material from said target onto said plurality of instruments, discontinuing deposition of said first material prior to deposition of about 500 angstroms of coating thickness thereof on said edge portions, thereafter positioning at least one target containing said second coating material in a closely overlying relation to said at least one electrode, positioning said carrier means such that said edges are in an at least partially facing relation to said target, impressing a radiofrequency alternating voltage gradient between said electrode and a reference point sufficient to cause significant electron flow in said evacuated region adjacent said electrode, introducing a minute amount of an inert gas into said evacuated area, whereby said flowing electrons ionize some of the molecules of said inert gas to form a plasma, and whereby the ions from said plasma strike said second, organic plastic material and sputter said material from said target onto said plurality of instruments, and discontinuing said process prior to deposition of about 2,000 angstroms of coating thickness of said second material on said edge portions.

2. A method as defined in claim 1 wherein said organic plastic material comprises a halogen-containing polymer.

3. A method as defined in claim 1 wherein said organic plastic material comprises a fluorocarbon polymer.

4. A method as defined in claim 1 wherein said organic plastic material comprises a polymer of tetrafluoroethylene.

5. A method as defined in claim 1 wherein said organic plastic material comprises a hydrocarbon polymer.

6. A method as defined in claim 1 wherein said organic plastic material comprises polyethylene.

7. A method as defined in claim 1 in which said second organic plastic coating material undergoes at least partial change of molecular weight in being removed by said sputtering from said target and being deposited on said edges on said instruments.

8. A method as defined in claim 1 wherein said at least one electrode comprises a pair of electrodes in the form of generally flat plates, adapted to receive similarly shaped targets over the surfaces thereof, said electrodes being positioned with their upper edges parallel and closely spaced apart to form a peak and their lower edges farther spaced apart so as to form a downwardly directed opening, and wherein positioning said plurality of instruments comprises moving said instruments into the area generally immediately beneath the opening formed in said peak.

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