

[54] GLOW DISCHARGE COATING APPARATUS
 [75] Inventors: James F. Carpenter, St. Louis; Leon E. McCrary, Bridgeton; Kenneth E. Steube, St. Charles; Albert A. Klein, Jr., St. Louis; George H. Kesler, Creve Coeur, all of Mo.

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[73] Assignee: McDonnell Douglas Corporation, St. Louis, Mo.

Primary Examiner—Morris Kaplan
 Attorney—Charles B. Haverstock

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 117/93.1 GD, 93.1 CD; 250/49.5 R;
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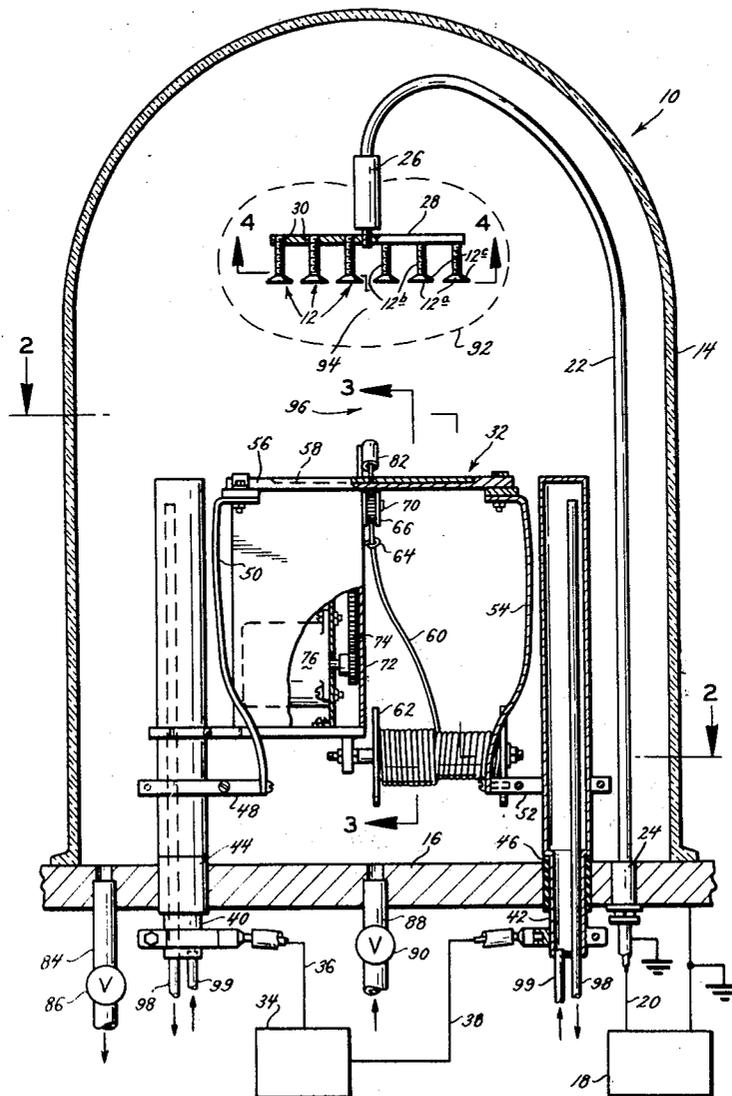
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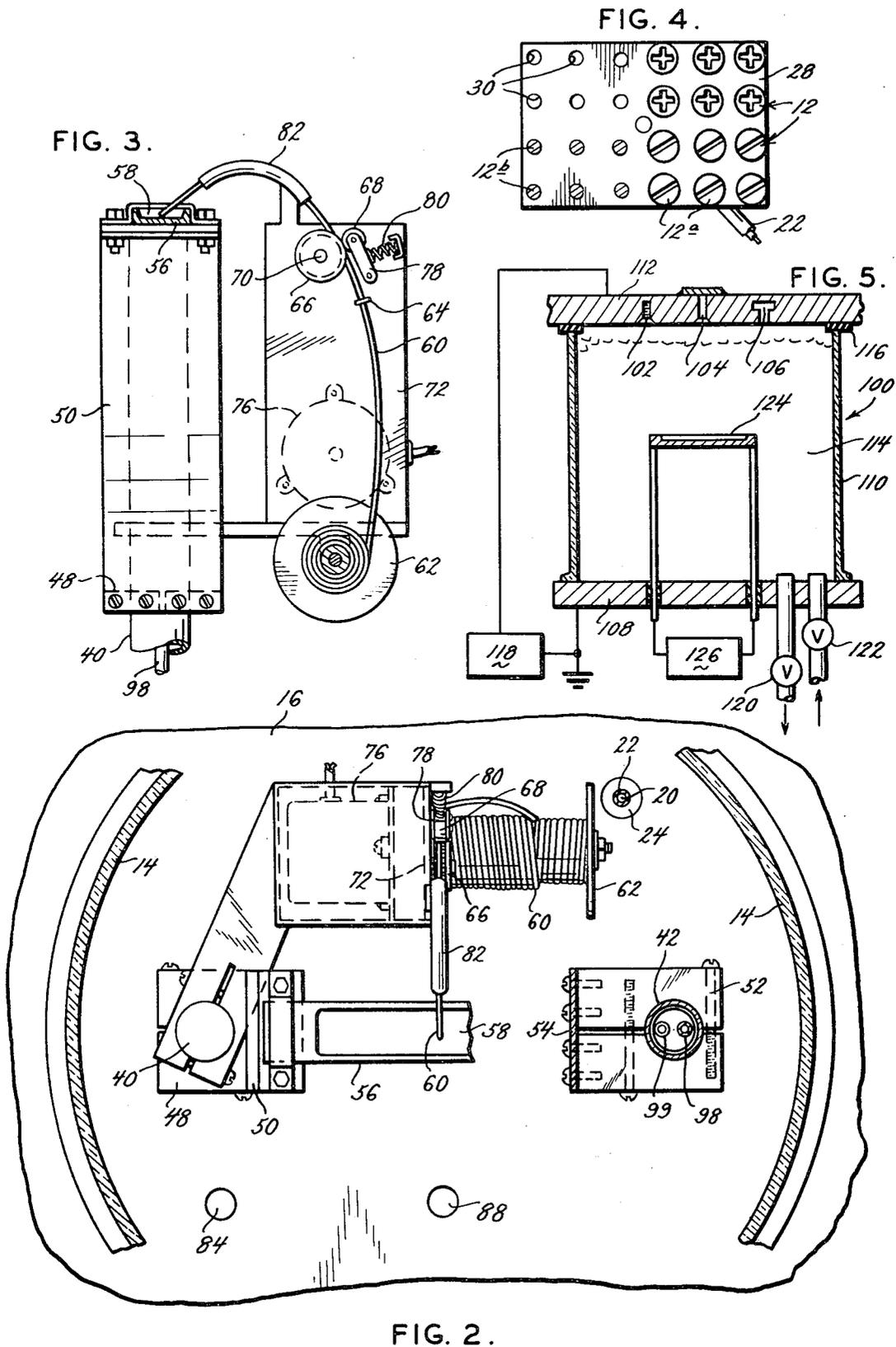
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[57] **ABSTRACT**

An apparatus for plating workpieces including particularly irregularly shaped workpieces by exposing said workpieces to controlled environmental conditions including an atmosphere of inert gas, ionizing particles of the gas in the presence of a relatively high voltage electric field whereby the ionized particles of inert gas are attracted toward and bombard the workpieces thereby cleaning and preconditioning the workpieces, and simultaneously vaporizing particles of a plating substance into the controlled environment whereby some of said vaporized particles are ionized, and both neutral and ionized particles are deposited on the surfaces of the workpieces including surfaces which may be hidden from line-of-sight of the source of vaporized particles.

11 Claims, 9 Drawing Figures





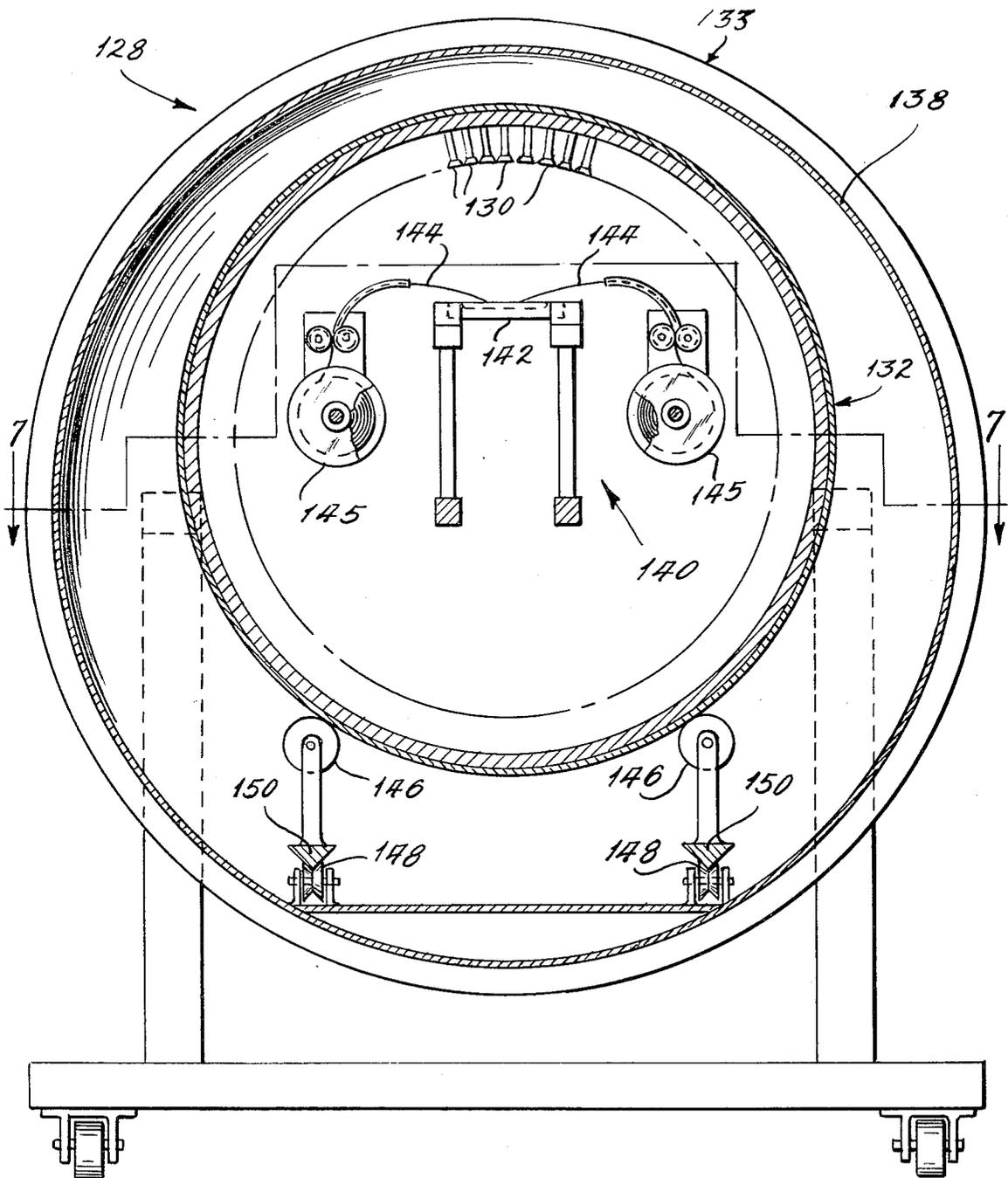


FIG. 6

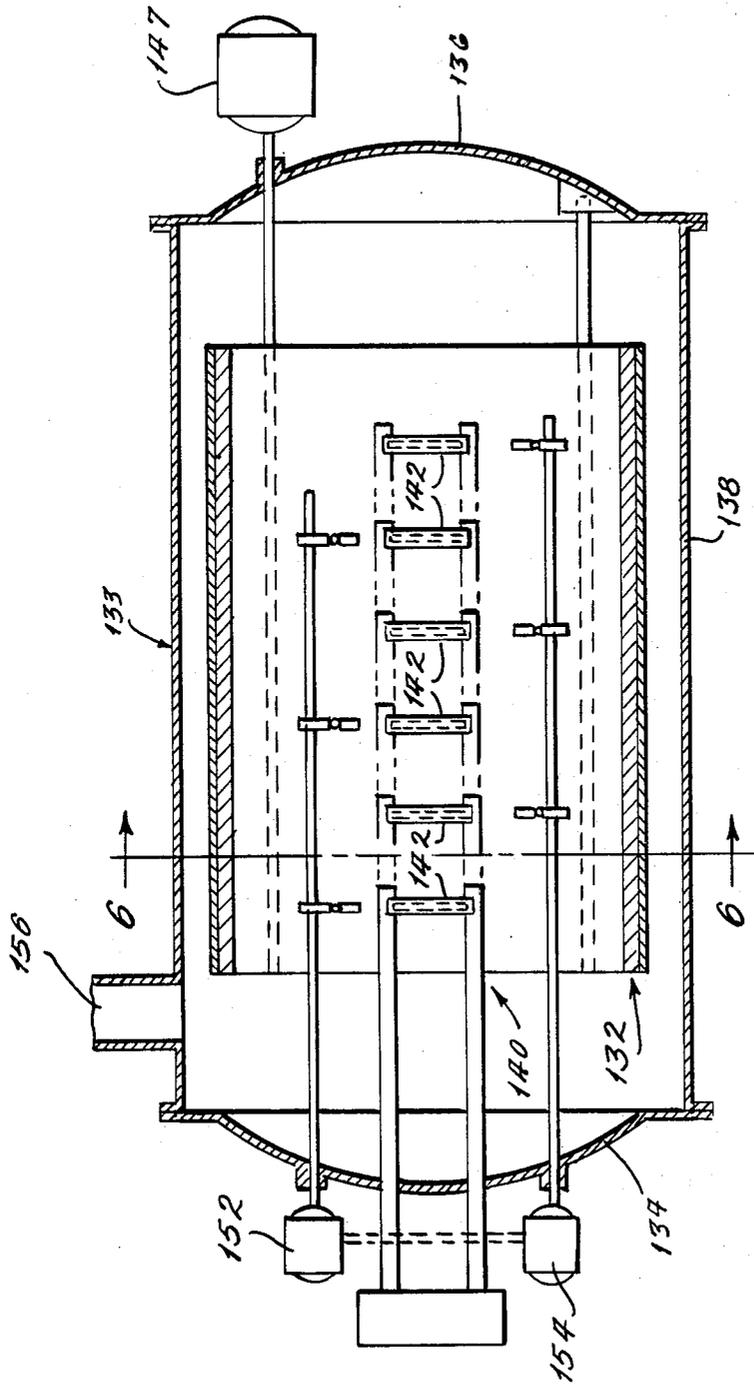


FIG. 7

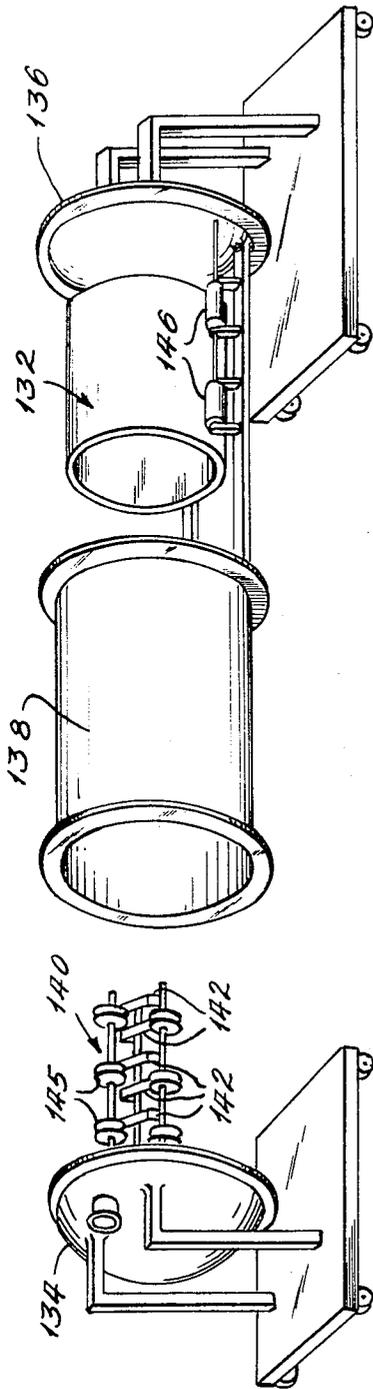


FIG. 8

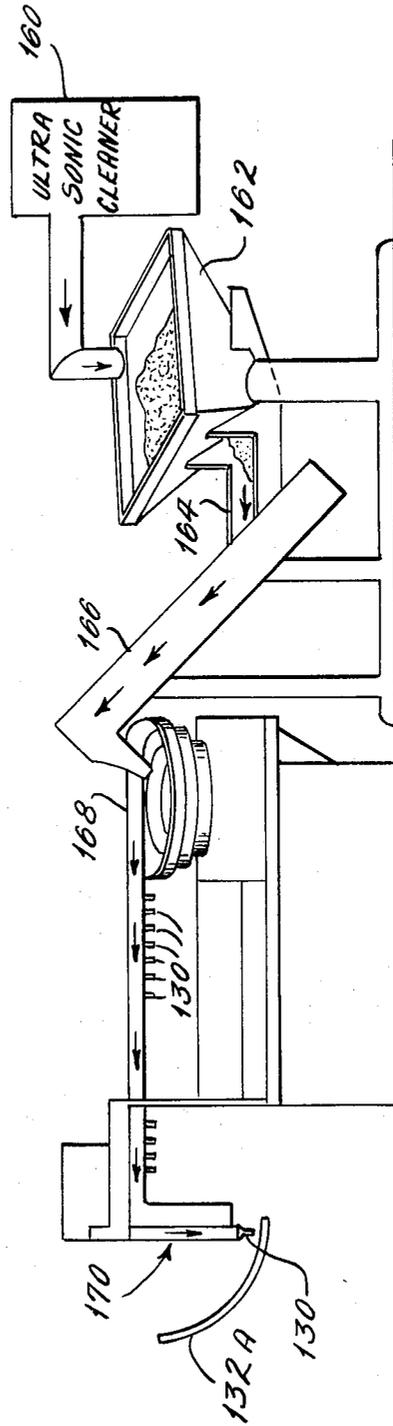


FIG. 9

GLOW DISCHARGE COATING APPARATUS

This is a Continuation-In-Part of our earlier filed co-pending application, Ser. No. 751,499, filed Aug. 9, 1968, assigned to the same assignee and now abandoned.

There are many reasons for wanting to plate or coat articles or workpieces with a layer of a plating substance including to protect workpieces from hostile environments which might cause deterioration. It is also often desired to be able to plate workpieces without substantially changing their size and shape and without weakening them. There are also cases where it may be desired to plate certain portions of workpieces such as the portions that will be more exposed when in use with a thicker coating or plating than other portions which are not as likely to be exposed. Threaded fasteners such as screws and bolts used to attach the skin and other exposed parts of air and space vehicles are examples of workpieces on which it may be desired to plate certain portions such as head portions thicker than other portions such as the thread and shank portions. There are many known and available plating apparatus and processes but none so far as known has solved the problem of plating all surfaces of irregularly shaped objects or workpieces including plating surfaces hidden from view of the plating substance, and none plates certain portions of workpieces thicker than other portions thereof in a controlled manner. For the most part, the known plating apparatus and processes have also left something to be desired as far as the strength of bond formed between the plating layers and the workpieces. Furthermore, all known vacuum plating processes and apparatus which vaporize a plating substance employ line-of-sight or substantial line-of-sight operation between the source of vaporized particles and the workpiece surfaces to be plated. This has limited the usefulness of known plating apparatus and methods to plating more or less regular surfaces or at least surfaces that have substantially their entire area to be plated exposed or in line-of-sight with the particle source. This limitation of the known means has limited the kinds of workpieces that can be plated or has necessitated the requirement of some complicated mechanism for moving the workpiece relative to the substance being vaporized so that all surfaces to be plated are exposed thereto, or it has meant that the workpiece and/or the source must be relocated relative to each other if another surface portion of the workpiece is to be plated. Means for producing relative movement between a source of vaporized particles and a workpiece especially in a controlled environment condition are relatively complicated and expensive and any relocating of the workpiece or source to plate other surfaces on the workpiece is time consuming and likely to produce non-uniformly plated workpieces. In some forms of the present device, however, particularly where it is desired to mass produce large quantities of plated members such as threaded and unthreaded fasteners in a continuous and uninterrupted operation some relative movement between the source of plating substance and the objects to be plated may be desirable and justifiable expense-wise and such means are disclosed in this specification.

These and other limitations and disadvantages of the known apparatus and processes are overcome by the present invention which teaches the construction and operation of a novel apparatus and process capable of

being used to simultaneously plate all surfaces on one or on a plurality of articles some or all of which may have surfaces which are hidden from view of the source of plating material. The subject apparatus therefore provides means by which it is possible to plate substantially the entire surfaces of the workpieces irrespective of their shape and with or without moving or relocating the workpieces or the source during the plating operation and where some surface portions to be plated may at all times be out of line-of-sight of the source of plating material. The present apparatus also provides means by which a thicker plating can be applied to certain areas of workpieces than to other areas, and layers applied to workpieces by the present process are attached or bonded more securely because of the cleaning action that also takes place and the layers are therefore less likely to crack or chip off than layers applied by other known processes. In addition to the above advantages the present plating process also takes place faster and is able to produce thicker plating layers in a given time than known processes used for the same or similar purposes, and without requiring as much attention and labor on the part of an operator.

It is therefore a principal object of the present invention to provide an improved apparatus for plating workpieces and particularly workpieces having irregular shapes with some surface portions that may be hidden from the source of plating material.

Another object is to provide means by which certain portions of a workpiece surface can be coated to a greater thickness than other portions thereof.

Another object is to provide means by which a plurality of workpieces, all of which may have irregular shapes, can be plated simultaneously.

Another object is to provide means for producing an improved bond between workpieces and plating surfaces applied thereto.

Another object is to provide means for depositing vaporized particles of a plating substances on all or substantially all surfaces of a workpiece including surfaces in and out of line-of-sight with the source of vaporized particles.

Another object is to reduce the time and labor required to plate workpieces using an ion vapor deposition technique.

Another object is to simplify the mechanism required to support a workpiece during plating thereof.

Another object is to provide means that can be used to plate all or any part of a workpiece.

Another object is to provide means for producing improved fasteners and like devices which can stand up to extreme environmental and other conditions without deteriorating.

Another object is to provide means for surface plating metallic as well as non-metallic workpieces.

Another object is to provide means for producing an abundant continuous supply of a vaporized plating substance so that an uninterrupted plating operation can be performed.

Another object is to provide relatively inexpensive and easy to operate means for plating irregularly shaped objects such as screws, bolts, rivets, threaded holes and other like devices.

Another object is to minimize the labor required to plate objects.

These and other objects and advantages of the present invention will become apparent after considering

the following detailed specification which discloses several preferred embodiments thereof, in conjunction with the accompanying drawings, wherein:

FIG. 1 is a cross-sectional elevational view of a work-piece plating apparatus constructed according to the present invention;

FIG. 2 is a cross-sectional view taken on line 2—2 of FIG. 1;

FIG. 3 is a cross-sectional view taken on line 3—3 of FIG. 1;

FIG. 4 is a view taken on line 4—4 of FIG. 1;

FIG. 5 is a cross-sectional view showing a modified form of the apparatus shown in FIG. 1;

FIG. 6 is a cross-sectional view taken through another modified embodiment of the subject device particularly designed to mass produce plated members such as fasteners and the like;

FIG. 7 is a cross-sectional view taken on line 7—7 of FIG. 6;

FIG. 8 is an exploded view showing the main components of the modified construction of FIG. 6, and;

FIG. 9 is a schematic diagram showing a means for loading elements to be plated on a support carrier therefor.

Referring to the drawings more particularly by reference numbers, number 10 in FIG. 1 refers to an apparatus constructed according to the present invention and designed particularly to be used to plate objects such as threaded fasteners 12 or the like, using a process sometimes referred to as ion vapor deposition. The process known as ion vapor deposition (IVD) is to be distinguished from other known plating processes including processes known as chemical vapor deposition (CVD) and physical vapor deposition (PVD). Chemical vapor deposition, for example, is a process whereby a volatile metal-bearing compound is vaporized and the vapor transported to a heated substrate on which it forms a deposit. In chemical vapor deposition thermal energy associated with a substrate is used to disassociate a vaporized or gaseous compound leaving a deposit of only the plating metal on the substrate. Physical vapor deposition, on the other hand, is a process whereby the metal to be deposited is vaporized and forms a deposit as it condenses on a relatively cool substrate or workpiece. This process is sometimes also called vacuum metalizing.

Ion vapor deposition which is employed in the present invention employs a direct-current discharge which is established between spaced elements such as between an anode and a cathode in a controlled environment such as in a relatively low pressure inert gas environment. In ion vapor deposition the substance or metal to be deposited, as will be explained, is vaporized in the positive glow region of the discharge and a portion of the evaporated metal particles or atoms are ionized before reaching the substrate. The evaporated particles including the ionized particles as well as the neutral metal particles or atoms are then deposited on one or more workpieces which in the subject process are attached to the negatively charged side or cathode of the direct current discharge means. This is described in detail in this specification. Also and importantly, the apparatus and process of the present invention will be described in connection with coating irregular shaped objects such as the threaded fasteners 12 where it is desired to apply a plating layer over all or substantially all of the surfaces of one or more of the fasteners 12 at a

time including those surface portions which are in line-of-sight of the evaporant source as well as those surface portions which are not so directly exposed to the source.

The device 10 as disclosed in FIG. 1 includes a bell-jar 14 which is sealed to a conductive base 16 by suitable means. The device also includes a relatively high negative voltage source of electrical energy 18 which is connected to a lead 20 which is shown extending through a tubular member 22. The tube 22 also extends through a hole in the base 16 and is sealed thereto by a suitable dielectric insulating member 24. The portion of the tube 22 that is inside the bell-jar 14 has a semi-circular shaped upper end portion with its free end centered in the bell-jar 14 and connected to an end member or cap 26. The high voltage lead 20 extends through the tube 22 and through the cap 26 and is insulated therefrom by suitable means, and the free end of the lead 20 is also connected electrically to a work-piece holder or cathode structure 28. This means that the cathode structure including the attached workpieces to be plated are maintained at the potential of the source 18 which is a relatively high negative potential relative to the potential of the base 16 and other structure some of which is shown grounded. The opposite side of the high voltage source 18 is also shown grounded to the base.

The cathode 28 is shown for illustrative purposes as being a plate-like member having a plurality of spaced threaded holes 30 therethrough which receive the threaded end portions of the threaded members 12 to be plated. The threaded members or fasteners 12 are attached to the cathode 28 by screwing them into the holes 30 with their head ends 12a extending downwardly toward a source of metal particles identified generally by the number 32. It should be noted that the shank and threaded portions 12b of the fasteners 12 as well as the adjacent sides 12c of the head portions 12a are hidden from and therefore out of direct line-of-sight of the source of evaporated particles 32 which are to be deposited thereon. However, even though certain portions of the workpiece surfaces are out of sight of the source 32, the subject apparatus is still able to apply a plating layer to all surfaces of the workpieces 12 except possibly the portions that are actually threaded into the cathode plate 28. This is an important aspect of the invention and one which has not been possible or even recognized or made use of heretofore with any known vacuum plating process.

In part the ability of the present apparatus and process to plate all surfaces of workpieces including those hidden from the particle source is due to recognition and use of certain characteristics of ion vapor deposition including particularly use of the much greater throwing power which can be achieved as will be described later.

Another relatively low voltage source of electric energy 34 is also included in the present device and is made use of to vaporize the plating substance. The low voltage source 34 is connected by leads 36 and 38 to tubular conductors 40 and 42 respectively, which extends through the base 16 and are insulated therefrom by suitable dielectric insulating members 44 and 46, respectively. Mounted on the tubular conductors 40 and 42 within the bell-jar 14, respectively, by terminal blocks 48 and 52 are resilient, relatively easily deflectable conductor straps 50 and 54. The straps 50 and/or

54 are made resilient intentionally so that expansion and contraction of the evaporation boat 56 to which they are attached will not cause their connections to the boat to move or to loosen. This is highly desirable in a device such as the present device where the boat is repeatedly subjected to wide temperature variations. The upper portion of conductor straps 50 and 54 are secured to the boat 46 by suitable means such as by threaded fasteners 57 or like means with or without associated nuts and lock washers. The boat 56 has a cavity or depression 58 in its upper surface that is shaped so that it will hold or contain a relatively substantial quantity of the plating substance which is continuously melted therein and then evaporates as a plating operation continues as required.

The plating substance, which may be selected from various substances, is shown being in the form of an elongated member or wire 60 wound on a spool 62. The free end of the wire 60 is fed through an eyelet 64 and then is fed between spaced friction rollers 66 and 68 (FIG. 3). The roller 66 is the driver roller and is mounted on a shaft 70 which extends through a housing wall 72. The shaft 70 also has a gear (not shown) mounted on it and the gear meshes with other gears in a gear train 74 (FIG. 1) which is driven by a motor 76. The other friction roller 68 is mounted on a pivoted arm 78 attached to the housing wall 72 and is biased by spring 80 toward the friction roller 66 and toward the wire 60 which is positioned therebetween. The free end portion of the wire 60 also extends through a curved tube 82 which is constructed to direct the end of the wire into the boat cavity 58. When the motor 76 is energized the friction roller 66 is rotated and applies pressure on the wire 60 to advance it toward the boat 56 which when heated melts and evaporates the wire as it is fed. In this way a continuous supply of the plating material is available and is evaporated for plating the workpieces.

Referring again to FIG. 1, the subject apparatus has a conduit 84 which communicates with the inside of the bell-jar 14 and with the vacuum or suction side of a pump (not shown) through a valve 86. The pump is used to evacuate the bell-jar 14 during the preparation of the environment for the inside thereof. The pump is operated in the first instance to evacuate the inside of the bell-jar and to produce a near vacuum condition therein. Thereafter, a source of inert gas is fed through another conduit 88 and another valve 90 into the bell-jar 14. Any suitable inert gas can be used to back fill the chamber after the chamber has once been evacuated. The chamber is usually back filled to a pressure of about one atmosphere and then is reevacuated to a pressure of around ten to twenty microns which is then made up almost entirely of the selected inert gas. A dynamic system pressure is maintained by continuing a controlled flow of the inert gas through conduit 88 while at the same time continuing a controlled evacuation of the system through conduit 84. Thereafter, the high negative voltage is applied to the cathode 28 and to the workpieces or other parts to be plated which are attached thereto. This causes a negative glow 92 to be established in the vicinity of the cathode and ionizes some of the particles of the inert gas. The positively ionized gas particles are attracted to the cathode and to the workpieces 12 which they bombard from all directions. This bombardment cleans and conditions the workpieces to receive a deposit of the evaporated plat-

ing substance. In order to produce the negative glow a relatively high negative potential in the range of approximately -5,000 volts with respect to ground must be applied to the cathode 28. The glow discharge 92 established around the cathode 28 and the accompanying ion bombardment of the workpieces is maintained throughout the plating process and operates to continuously clean and condition the workpieces. Between the glow discharge and the cathode is a region 94 sometimes called the "cathode dark space."

Once the glow discharge is established and has been in operation for some time, the boat 56 will be heated by the low voltage source 34 to a temperature at which the plating substance will vaporize. Most of the vaporized substance will be present in the region extending between the boat and the cathode in the region 96 referred to in FIG. 1. Some of the vaporized substance will be ionized by the action of the charged environment and some will remain as neutral particles or atoms. The tubular conductors 40 and 42 in the circuit that provides electric energy to the boat 56 are shown in FIG. 1 as hollow closed end tubular members. This is so that they can accommodate conduits 98 and 99 which are provided to circulate a coolant in the members 40 and 42 to control the operating temperature of the electrical connections between the conductor straps 50 and 54 and the boat 56 and to control the operating temperature of the tubular conductors 40 and 42. These can also be used to control the temperature in the bell-jar 14.

The pressure of the inert environment, the electrical potential on the cathode 28, the temperature of the boat 56, the evaporation rate and feed rate of the plating substance, the temperature of the workpiece, the spacing between the boat and the cathode, and the position and relative positions of the parts in the bell-jar 14 are all variables which can be adjusted to obtain optimum plating conditions. Following is a brief summary tabulation of the average thickness of metal platings applied to steel fasteners. The aluminum coating was applied by the ion vapor deposition process to obtain an optimum distribution of coating thicknesses. The coating is greatest on the head, for maximum resistance to corrosion and wear and to provide protection from tools used to fasten them in place, while the coating in the other areas is thinner to meet tolerance requirements and to enable coating standard sized elements without substantially effecting their dimensional characteristics. The cadmium coating, on the other hand, was applied by a known standard electroplating method and is used for purposes of comparison. In the tabulation similar fasteners were used in all cases, and in the case of the aluminum coated fasteners, the head ends of the fasteners faced toward the source of evaporated plating material contained in the boat and the other portions of the fasteners including the tapered countersink portions opposite the head ends, and the shank and threaded portions were hidden from or out of line-of-sight of the source of plating material.

Fastener Coating	Head Ends (mils)	Countersink (Mils)	Shank (Mils)	Thread (Mils)
Aluminum	0.93	0.45	0.45	0.29
Cadmium	0.50	0.85	0.40	0.40

This tabulation illustrates how the plating thickness can be varied over the entire surface of the fasteners and the results tabulated for the aluminum coated fas-

teners were obtained without having any relative movement between the plating substance or boat and the fasteners. The tabulation is illustrative only and is not intended to cover all possible plating materials or operating conditions. Likewise it is not intended to limit the invention to plating threaded fasteners since there are many other applications and uses where similar platings may be desired for some reason. Plating layers applied as herein described in addition to providing protection from hostile environments and conditions including outer space can also be used to provide protection from oxidizing environment, to improve the wear characteristics, it can be used for deposition of diffusion aids, to improve the friction characteristics of a workpiece, provide a metal coating for a dielectric member or element such as are used in high temperature devices such as antennae and the like, and it can be used for many other applications and purposes.

As already stated, when the device of FIG. 1 is operating some of the vaporized particles will be ionized and some will remain as neutral particles or atoms. Those particles which are ionized will have a greater attraction for the negatively charged cathode 28 and for the workpieces 12 than the neutral particles and will therefore be relatively rapidly accelerated thereto. Many of the neutral particles will also move toward the workpieces and together with the ionized particles will form the plating layers thereon. Thus the workpieces 28 will be simultaneously bombarded and cleaned by the ionized particles of the inert gas while at the same time atoms and ions of the plating material are being deposited thereon. In order for a layer of the plating material to form the rate of deposition of the plating substance must take place faster than the cleaning action described and this condition can be obtained by adjusting the boat temperature and other operating conditions. It is important to recognize, however, that the simultaneous occurrence of the cleaning and depositing actions in addition to the relatively high energy of impact of some of the particles of the plating substance cause the particles which form the plating layer to be bonded to the workpieces by a diffusion or diffusion-like bond which substantially improves the connection therebetween.

This dual action is to be distinguished from other known plating processes such as those which involve sputtering wherein the particles to be deposited are dislodged from a cathode element constructed of the desired plating material by bombarding the cathode with ions of some substance such as an inert gas. The particles thus dislodged in the typical sputtering process leave the cathode and travel toward and form a deposit on a substrate. In the present process the inert gas particles which are present perform a cleaning operation which is important to prepare the surfaces of the elements to be plated to receive the plating layer which is made available from an entirely separate vaporized metal source. In the present case the element or elements to be coated are therefore not only thoroughly cleaned and prepared by the action of the inert gas but the inert gas also serves to back-reflect vaporized particles of the plating substance toward the workpiece to plate areas which are not in line-of-sight of the source of the vaporized particles. This is the principal factor which produces the throwing power feature which is so important to the present device.

The cleaning action produced by the inert gas is usually commenced before the temperature of the boat is raised sufficiently to vaporize the plating substance. Thereafter, the temperature of the boat 56 is increased by increasing the voltage thereacross by suitable means on the low voltage source 34 so that particles of plating material are deposited on the workpieces at a faster rate than the cleaning action takes away material so that a deposit is able to accumulate.

During the process those particles of the plating substance which are ionized will accelerate toward the workpieces and it is anticipated that under some circumstances they may actually penetrate the surfaces of the workpieces. This condition can be controlled and in many cases is desirable because it helps to create a type of interface similar to one formed by diffusion between the plating layer being formed and the workpieces being plated. This is desirable to the formation of a good diffusion type bond between the workpieces and the overlap and helps to prevent the overlayer from coming loose or cracking.

The present apparatus and method of plating has particular application in cases where it is desired to plate irregularly shaped workpieces such as the screws 12 shown in FIGS. 1 and 4. This is true because with the present apparatus and method the workpieces can be plated over their entire surfaces including portions of the workpieces that are hidden or partially hidden from the source of vaporized particles. Also, screws and like devices can be plated so that certain portions will have a thicker plating applied than other portions. This difference in plating thickness can also be controlled by selection of the various operating conditions. For a threaded fastener or screw this may be highly desirable because it affords a means for plating portions thereof which may need more protection such as the head portions with a thicker plating layer than other portions which may not need as much protection. Also, portions such as the threads usually should not be plated too thick because of size and tolerance limitations. In a typical case a thickness ratio of approximately two to one between the head end and the thread and shank portions may be very desirable. The present invention provides means for obtaining this or other ratios by selecting the desired operating conditions which control and determine the throwing power. One of the conditions which has the greatest effect on throwing power is the pressure of the inert gas environment, another is the temperature of the parts to be plated, another is the voltage applied to the cathode, and still another has to do with the positions relative to each other of the parts to be plated and with the relationship of the components employed including the relative positions of the boat and the cathode structure. These and other conditions should be adjusted to produce the desired or optimum plating conditions including the optimum deposition rate, the optimum penetration of the substrate or element being plated, and the optimum throwing power. Regarding throwing power, it is also to be noted that greater throwing power is achieved by having an inert gas environment than is obtainable in a vacuum. The increase in throwing power is explained in part by the fact that some of the metallic atoms of the vaporized substance are reflected by collisions with the inert gas particles and are deposited on hidden surfaces of the workpieces. The attractive power of the relatively high negative potential on the cathode 28 for the por-

tion of the vaporized substance which is ionized may also be a factor in improving coverage of the plating on complex surfaces.

Tests to date have demonstrated the superiority of fasteners plated by the subject method and apparatus over fasteners plated by other methods and apparatus. This is especially so when comparing corrosion and exfoliation characteristics around fasteners used for attaching panels, and skins to air and space vehicles.

FIG. 5 discloses another embodiment 100 of the subject device which is similar to the embodiment discussed above but is used to specifically plate surfaces of holes, cavities and recesses such as the threaded hole 102, the non-threaded hole 104, and the recess or cavity 106. The structure of the device shown in FIG. 5, like the structure of FIG. 1, includes a grounded base 108 and instead of having a bell-jar has a closed side wall member 110 which may be glass as shown sealably attached to the base 108. The modified structure also has another conductive wall member 112 which in this case is the workpiece that has one or more holes or cavities therein which are to be plated. The members 108, 110 and 112 are sealably connected to one another to define a chamber 114 in which the plating process takes place. It may also be necessary to seal the side wall member 110 to the wall 112 by some means such as insulating means 116. A high negative voltage from a source 118 is applied to the wall 112 and the wall 112 therefore serves as the cathode for the modified structure of FIG. 5. The structure 100 also includes pump means (not shown) and valve means 120 for evacuating the chamber 114, other valve means 122 in a line to a source of inert gas, and a boat 124 which is connected across a relatively low voltage energy source 126. Except for the fact that the modified structure 100 is primarily for plating the surfaces of holes and cavities instead of plating external surfaces of devices such as fasteners and the like, it is similar and operates similarly to the structure described above and shown in FIGS. 1-4. It is also to be noted in connection with the modified structure 100 of FIG. 5 that the more exposed surfaces of the holes and cavities such as the portions that face the boat 124 may be plated thicker than the other less exposed portions. This may be desirable in some cases.

FIGS. 6-8 illustrate another embodiment 128 of the subject device designed specifically to be used to mass produce fasteners such as the threaded fasteners 130 (FIG. 6). In this case, the fasteners 130 are mounted with the head ends extending inwardly on a rotating drum or insulated metal cage 132 which serves as the cathode and is shown as being an open ended cylinder. The cylinder 132 is mounted for rotation inside of a larger diameter housing 133 formed by two spaced end walls 134 and 136 and a connecting open ended cylindrical housing wall 138. The rotating drum 132 has positions on it for accommodating many fasteners or other elements to be plated, even many thousands of fasteners to be plated in a continuous and uninterrupted operation. Positioned extending into the housing 133 and into the cage 134 from one end is a boat assembly 140 which includes a plurality of similar spaced evaporation boats 142, each of which is shown in FIGS. 6 and 7 constructed to include means to receive a continuous supply of the selected plating material 144 from a source such as a spool 145 shown located on one side of the respective boats. The spools

145 and their associated feed mechanisms for feeding the plating materials to the adjacent boats are shown staggered for convenience in locating them.

The cage 132, but not the boat assembly 140, is mounted inside the housing 133 for rotation on pairs of spaced rotatable members 146 (positions for two pairs being shown in FIG. 8). The rollers 146 are driven by means such as motor means 147. The cage 132 and the rollers 146 may also be mounted for relative axial movement in the housing 133 on spaced other rollers and tracks 148 and 150 as shown in FIG. 6 to facilitate assembly and removal of the cage 132 from the housing 133 for loading and unloading purposes. Except for the fact that the modified construction shown in FIGS. 6-8 is constructed to coat or plate many thousands of fasteners or other relatively irregular shaped objects in a continuous and uninterrupted operation and under environmental conditions similar to those described above in connection with the structure shown in FIGS. 1-5, the modified device is similar and operates similarly thereto. Note, however that in the modified structure the high voltage is applied to the cage 132 and the heater voltage is applied to all of the boats. Also, in FIG. 7 the two variable speed motors 152 and 154 are included to feed the wires 144 of coating material to the respective boats during operation to continuously provide a supply of evaporated coating material. Vacuum pumping and other control means connected to the modified device by conduit 156 are also included and may be similar to those described above for the other constructions.

FIG. 8 shows the major components of the modified construction in an exploded form for easy understanding.

FIG. 9 is a schematic view showing a typical machine used for automatically loading fasteners or other devices to be plated on the cage 132 prior to its installation inside the housing 133. The loading means are shown loading one of four equal quarter portions of the drum 132 and includes ultra-sonic means 160 for cleaning the fasteners and feeding them to a funnel-type bin 162. From the bin 162 they are sent by conveyor means 164 and 166 to an orientor device 168 which is shown as being helical in shape. Here they are oriented and aligned automatically and fed to another unit 170 which includes means for threadly or otherwise attaching them to the cage section 132A.

The loading of the cage 132 can also be done manually if desired, although it is usually preferred to load it automatically because of the anticipated relatively large numbers of fasteners which are to be plated. In the modified plating construction shown in FIGS. 6-8 the fasteners are positioned to be head down as they move past above the boats 142 and the speed of rotation of the cage 132 during a plating operation is adjusted to be slow enough to enable plating of the parts to the desired thickness. It is apparent, however, that the cage will rotate slowly and continuously during a plating operation so that all of the fasteners will be similarly plated. In actual operation a 30 inch diameter cage 36 inches long will be able to accommodate approximately 5,000 to 6,000 fasteners. Experience has also shown that a typical coating cycle which is the time required to rotate the cage through one complete rotation requires approximately 45 minutes. This can obviously be varied substantially depending upon the plating thicknesses required, the materials involved, and

the environmental and other conditions that are maintained.

Thus there has been shown and described several embodiments of novel means and methods for plating objects and particularly objects that have irregular shaped surfaces, which means and methods fulfill all of the objects and advantages sought therefor. Many changes, modifications, variations, alterations, and other uses and applications for the present means and methods, however, will become apparent to those skilled in the art after considering this specification and the accompanying drawings. All such changes, modifications, variations, alterations, and other uses and applications which do not depart from the spirit and scope of the invention are deemed to be covered by the invention which is limited only by the claims which follow.

What is claimed is:

1. Means for plating objects and particularly objects having irregular shapes such as fasteners that have head end and connected shank portions such that it is not possible to see all of the surfaces to be plated from any one observation point comprising means forming an enclosed chamber, a cathode member having means thereon cooperatively engageable by at least a portion of a fastener device to be plated so as to position and support said fastener in said chamber, means for evacuating the chamber to establish a near vacuum condition therein, other means for introducing an inert gas into the evacuated chamber to raise the pressure in the chamber to a predetermined level, a supply of plating substance positioned in spaced relationship to the fastener in the chamber, said supply of plating substance including an evaporation boat, a source of heater voltage and means connecting said source of heater voltage across the evaporation boat for heating said boat to vaporize the substance positioned therein to an extent which causes the substance to vaporize, said source of heater voltage being connected to the boat by flexible and resilient conductor straps, said straps providing the support for the boat whereby expansion and contraction of the boat can take place without adversely affecting the connection between the boat and the source of heater voltage, means to continuously feed more of the said plating substance to the boat during a plating operation to maintain a vapor of said substance in the chamber, at least a portion of the head end of the fastener to be plated being in a direct line-of-sight of the boat and at least a portion of the shank of the fastener being out of direct line-of-sight of the boat, and means for establishing a relatively high negative potential on the fastener relative to the potential at said supply of plating substance whereby the inert gas is partially ionized in a region around the fastener so that some particles of said ionized gas are attracted to and bombard the fastener producing a cleaning action on the exposed surfaces thereof, and means to adjust the vaporizing temperature of the boat so that some of the vaporized particles of the plating substances are able to accumulate and form a deposit on said fastener, the particles landing on those portions of the fastener that are in line-of-sight of the boat accumulating more rapidly to produce a thicker plating layer than particles accumulating on portions of the fastener that are out-of-line of sight of the boat, the rate of plating of the surface portions of the fastener that are out-of-sight of the boat being controlled in part by the inert gas environment

including the pressure of the inert gas, the kind of inert gas and the selection of the plating substance.

2. The means for plating objects defined in claim 1 wherein said source of plating substance includes a spool having a coil of said plating substance wound thereon, and means for feeding said winding into the boat to maintain a continuous supply of the vaporized plating substance.

3. The means for plating objects defined in claim 1 including means for controlling the temperature of said conductor straps and of the environment in the chamber.

4. The means for plating objects defined in claim 1 wherein said means for positioning and supporting a fastener to be plated include a cathode element having means thereon including aperture means for respectively attaching a plurality of fasteners to be simultaneously plated.

5. The means for plating objects defined in claim 1 wherein said means for positioning and supporting a fastener to be plated include a cathode element having means thereon including aperture means for respectively attaching a plurality of fasteners to be simultaneously plated.

6. Apparatus for plating cavities and holes such as threaded holes in members comprising a member having a cavity or hole to be plated, said cavity having a surface defined by visible and hidden surface portions, means including said member forming a sealed chamber with said cavity or hole exposed therewithin, means for producing a near vacuum condition in the chamber, means for introducing inert gas into the chamber to establish an inert environment of predetermined pressure, a source of a plating substance positioned in said chamber in spaced relationship to said member, said substance source including a container and a supply of vaporizable plating substance in said container, a first controllable source of electric energy including means connecting said source across said container for heating said container sufficiently to vaporize the substance therein to cause said substance to evaporate at a selectable evaporation rate, said means connecting the source across said container including flexible and resilient conductor members for supporting the container in the chamber whereby expansion and contraction of the container can take place without affecting the connection between the container and the first energy source, a second source of electric energy including a relatively high negative voltage source, and means connecting said second source to the member having the cavity or hole to be plated, the presence of said relatively high negative voltage establishing a glow discharge and causing the inert gas environment in the vicinity of said member to be partially ionized so that some of the ionized gas particles are attracted to and bombard the visible and hidden surface portions of the cavity or hole to be plated thereby cleaning said surface portions, means to adjust the rate of evaporation of the plating substance so that particles of evaporated plating substance accumulate on and form a plating layer on the exposed surface portions of the member including said cavity or hole, some of the particles of the evaporated substance colliding with particles of the inert gas and being deflected thereby so as to land and accumulate on the hidden portions of the surface of said cavity or hole and some of the particles of the evaporated sub-

stance being ionized during transit and accelerated toward the said member to be plated, the rate of accumulation of the substance particles on the surface portions being greater on surface portions of the member that are in view of the vaporizing container than on the surface portions thereof that are not in direct line-of-sight of the container.

7. Means for plating objects having irregular shaped surfaces wherein certain portions of the objects are plated thicker than other portions thereof comprising a housing having a source of vaporizable plating substance therein, said source including a boat constructed of a relatively high impedance substance, means including a source of electricity connected across the boat to heat the boat to a temperature high enough to evaporate the plating substance, said connection across the boat including flexible and resilient conductor members, said conductor members providing the boat support whereby expansion and contraction of the boat can take place without adverse effect on said connection other means for continuously feeding a supply of the plating substance to the boat during a plating operation, a support structure positioned for movement in the housing, said support structure having a portion thereof extending in spaced relation above the boat, said support member having locations thereon for mounting a plurality of objects to be plated with the objects located on the portion of said support member above the boat and extending downwardly therefrom toward the boat, means for moving the support in the housing whereby different portions thereof move to positions above the boat, a source of relatively high negative potential connected to the movable support member whereby to establish a glow discharge and ionization of the vaporized plating substance, and means for establishing and maintaining a relatively low pressure environment of an inert gaseous substance inside said housing.

8. The means defined in claim 7 wherein the support member is a cylindrical member and the means for moving the support member include means for rotating the cylindrical member.

9. The means defined in claim 7 wherein the source of vaporizable plating substance includes a plurality of similar boats positioned in spaced relation.

10. The means defined in claim 7 wherein the support member is a cylindrical member having a plurality of threaded openings therein, the objects to be plated having threaded portions for cooperatively engaging respective ones of the threaded openings in the support

member.

11. Apparatus for simultaneously plating a plurality of fasteners such as screws, rivets, nails and other similar members which are characterized by having shank and head end portions comprising a container with a chamber therein, a tubular support member constructed in part of an electrically conductive material positioned in said chamber, said support member having an inner surface with a plurality of spaced means for cooperatively engaging the respective shank portions of the fasteners opposite from the head ends thereof to support the fasteners in positions thereon with their head end portions extending toward the center of the support member, means for rotating the support member inside of the container, a source of vaporizable plating substance positioned inside the container at a position inside of the support member, said source including a member having a hollowed-out portion in its upper surface, means for connecting a source of electric energy across the hollowed-out member, said means for connecting including flexible and resilient conductor elements, said elements providing the support for the source member, said hollowed-out member being constructed of a relatively high resistant material which will produce heat at least sufficient to vaporize a selected plating substance positioned therein, means for continuously feeding a supply of the selected plating substance to the hollowed-out member during a plating operating, means for establishing a relatively low pressure environment of an inert gaseous substance inside the container, a source of relatively high negative potential including means connecting said high potential source to the tubular support member and to the fasteners supported thereon, said high potential source establishing a glow discharge in the region of at least some of the fasteners supported on the tubular support member at a location above the hollowed-out member, and an accompanying cathode dark space between the support member and the hollowed-out member, said glow discharge being formed in part by ionized gas particles some of which are attracted toward the support member and the fasteners to be plated supported thereon whereby they bombard said fasteners and produce a surface cleaning action thereon, some of the vaporized particles of the plating substance within the chamber being ionized by the environment in the chamber and being accelerated toward the fasteners to be plated and forming an accumulation thereon.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,750,623 Dated August 7, 1973

Inventor(s) James F. Carpenter et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 39, "substances" should be "substance".

Column 4, line 11, "bp" should be "by".

Column 8, line 20, "overlap" should be "overlayer".

Column 9, line 4, "data" should be "date".

Signed and sealed this 25th day of December 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

RENE D. TEGMEYER
Acting Commissioner of Patents