ABSTRACT OF THE DISCLOSURE

A glow discharge apparatus is provided for treatment of nonuniform workpieces at uniform temperatures. The apparatus includes an outer metallic gas-tight chamber with an insulated cathode extending therein through a gas-tight insulated connection. A hollow electrically conductive container having a removable cover for insertion of the workpieces is disposed in the chamber and electrically connected to the cathode. A glow is induced on the interior walls of the container and surfaces of the nonuniform workpieces therein by providing an opening in the container wall large enough to prevent glow reinforcement within said opening as well as to admit the glow inducing means so as to act on the interior walls of the container. However, a means is arranged to prevent substantial radiation loss from the workpieces to the outside of the container through said opening.

This invention relates to an improved glow discharge apparatus for nitriding or otherwise treating a plurality of workpieces in a glow discharge at uniform temperature without regard to size, shape, material or arrangement of the workpieces within the apparatus.

Various arrangements have been disclosed for treatment of workpieces in the presence of a glow discharge, using various types of gases at low pressure inside a vacuum chamber. The gas ions subject the workpieces to high energy bombardment under the influence of the difference in electrical potential between anode and cathode to perform such operations as heating, nitriding, denitriding, etc. The energy lost by the bombarding ions serves to heat the workpiece (which is usually connected as the cathode) to an elevated temperature. The ultimate temperature attained by a particular workpiece is due to the energy lost by the ions plus the additional energy received by the workpiece by radiation from surrounding objects minus the radiation loss of the workpiece itself.

Since single workpieces are usually symmetrical, there has been little difficulty in obtaining uniform temperature in a glow discharge, since a single object can be arranged within a symmetrical glow discharge chamber so as to radiate, and to receive radiation in substantially the same manner in all directions. Difficulties arise in attempting to treat a plurality of objects uniformly with the glow discharge process, where it is desired that the objects attain uniform temperature. It has been proposed, in this regard, to arrange identical objects in a uniform and symmetrical manner so that each workpiece is disposed the same with respect to all other workpieces and the walls of the container in a radial pattern. This method is cumbersome and results in odd shaped glow discharge apparatus which is suitable only for workpieces of a given preselected shape.

It has also been known to employ suitably disposed radiation shields within the vacuum chamber to attempt to confine or reduce heat radiated from the object under treatment. Such radiation shields are partially effective, but great care must be exercised in placement of the shields, since their ultimate temperatures are primarily a function of radiation gains and losses, which are not easily predetermined.

Where a plurality of objects of nonuniform size, shape, and arrangement are to be treated, it has previously been difficult, if not impossible, to cause the various portions of the workpieces to achieve a uniform temperature. When nitriding in a glow discharge, for example, it is necessary to achieve this uniform temperature, in order to obtain a nitrided surface of uniform depth and quality, as well as to prevent distortion during the nitriding process. Also, it may occasionally be desirable to nitride objects of different material at the same time, and unless the temperature of the parts is accurately known, the result of the treatment cannot be accurately predetermined.

Accordingly, one object of the present invention is to provide an improved glow discharge apparatus suitable for treating a plurality of workpieces at uniform temperature in a glow discharge.

Another object of the invention is to provide apparatus for nitriding a plurality of objects in a glow discharge, the objects being of nonuniform size, shape, or arrangement within the apparatus.

Still another object of the invention is to provide an improved process for nitriding multiple workpieces in a glow discharge at uniform temperature.

The subject matter of the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both to organization and method of practice, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

FIG. 1 is an elevation view, partly in section, of glow discharge apparatus illustrating a preferred embodiment of the invention.

FIG. 2 is a transverse cross section of the apparatus, taken along lines II—II of FIG. 1.

FIGS. 3 through 7 are simplified schematic views of modified forms of the invention, and

FIG. 8 is a graph for aid in understanding the operation of the invention.

Briefly stated, the invention is practiced by completely surrounding the workpieces with a container which is connected as the cathode together with the workpieces so that it is also subjected to the glow discharge, and providing additional means enabling the glow discharge process to take place inside the container without substantially reducing the container's effectiveness as a radiation control device.

Referring now to FIG. 1, the drawing, a metal bell-shaped dome 1, cooled by suitable cooling tubes 2, is attached to a metal supporting base 3 by bolts (not shown) and provided with a gas-tight seal, such as O rings 4. Dome 1 and base 3 are of electrically conductive material, serve as an anode since they are connected to the positive terminal of a regulated power supply 5 providing in a DC voltage. A vacuum pump 6 and a regulated gas supply 7 provide for evacuation of the chamber and control of the treatment gas. For example, if the parts are to be nitrided, gas supply 7 will supply a suitable mixture of nitrogen and hydrogen, while pump 6 maintains the chamber at a few millimeters of mercury pressure.

The negative terminal of power supply 5 is connected to an internal cathode 8, via a metal plate 9 attached to base plate 3 and insulated therefrom by nylon screws 10 and an insulating plate 11. Cathode 8 is insulated from base 3 by an insulating tube 12, and the tube is protected from the glow discharge by a metal sleeve 13 at a "floating" electric potential.

Although the bell-shaped dome 1 and base 3 are connected as the anode, an auxiliary anode is provided by means of a thin metal cylinder 14 supported from the
In accordance with the invention, a plurality of non-uniform workpieces such as cylinder 15, rectangular prism 16, pyramidal-shaped member 17 are disposed in a thin metal container 18. It will be understood that "non-uniform" as applied herein means nonuniform as to size, or shape, or arrangement, or any combination of these. The container 18 is electrically connected to cathode 8. The workpieces 15, 16, and 17 are resting on the bottom of metallic container 18, so that container and workpieces are all at the electrical potential of the cathode 8.

Container 18 includes a removable cover 19, so that after the workpieces have been inserted, the container will completely surround the workpieces in so far as the possibility of radiant loss is concerned. However, it should be specifically noted that one or more holes 20 are provided in container 18 in order to allow the ions to migrate or move to the inside of the container. As will be more particularly noted in the description of the operation of the device, hole 20 should be large enough in relation to the size of the container so as not to interfere with ion movement in accordance with the various influences, such as gas charge, distance, and so on.

We have found that the diameter of the hole should be at least 1/2 of the distance from the hole to the most remote location inside the container. On the other hand, the hole should be as small as possible and so disposed in the container wall as not to allow substantial radiant heat loss therethrough as will be explained. If more than one hole is used, the number should be kept to a minimum.

Dotted lines have been used to indicate the presence of the glow layer which surrounds the objects 15, 16 and 17. The glow layer also surrounds container 18, both inside and out, since it is also connected as the cathode.

Reference to FIG. 2 of the drawing, illustrates a sectional plan view of the apparatus. In this figure, T4 represents the outside temperature of the vacuum dome 1, T9 represents temperature prevailing at the auxiliary anode 14, and T14, T18, T17 and T18 are temperatures prevailing at the respective cathode-connected parts. E4 represents the electrical potential at the anode, and E5 represents the electrical potential at the cathode.

The operation of the invention will now be described with reference to FIGS. 2 and 8. In FIG. 8, which is a conventional presentation of space charge distribution in a glow discharge, it will be seen that substantially all of the voltage drop occurs close to the cathode, while there is very little change in potential for most of the distance between anode and cathode. The foregoing graph of FIG. 8, of course, applies when a stable glow is in progress and is seen in practice by the fact that the brightest glow lies close to the surfaces of the cathode-connected members, as illustrated by dotted lines 15a, 16a, 17a, and 18a in FIG. 2. This illustrates the fact that, at a considerable distance from the anode and at a point almost up to the cathode, the space potential is still at a value approaching E4. However, since there is a slight drop in space potential from the anode to the inside of the container, there is a distinct influence causing the ions to move through hole 20 to the inside of the container.

Providing that hole 20 is made sufficiently large, the glow will take place inside of the container and there will be practically no reduction of the energy available for ion bombardment of the workpieces 15, 16 and 17, despite the fact they are not in direct line with the surrounding anode 14. In other words, by suitably selecting the size of one or more holes such as 20, the ions inside container 18 will still have substantially the same energy available for transforming the workpieces as if the container were not present.

Uniformity of temperature of all portions of workpieces 15, 16 and 17, despite their irregularity in size, shape, and disposition, is achieved by the fact that container 18 completely surrounds the parts and is itself connected as a cathode and also subjected to substantially the same glow discharge energy as the workpieces. Heat gains and losses by convection in this type of apparatus are negligible. Each member in the apparatus receives and gives up energy by mutual radiation from and to surrounding objects in accordance with the Stefan-Boltzmann law, where the net intensity of energy flow is proportional to the difference in absolute temperatures raised to the fourth power. Therefore, differences between the temperatures of workpieces 15, 16 and 17 and the temperatures of their surroundings would ordinarily cause great nonuniformity of temperature in such a nonsymmetrical arrangement.

In accordance with the present invention, the container 18 is subjected to the same glow discharge intensity as the members within the container. Initial variations in intensity of the radiation pattern from pieces 15, 16 and 17 as it falls on container 18 are believed to be eliminated by conductor and temperature averaging in the walls of the container. Hence its temperature T18 will be ultimately the same as and gas 8, regardless of the objects inside the container, i.e., T12, T14 and T17. Each object will "see" other objects at the same temperature and hence there will be no net radiant energy flow between container and the parts inside it. By this means, the irregularity of the workpieces is no longer of any consequence.

By utilizing the above specified thin metal container 18 and by providing the relatively large hole 20, glow reinforcement, sometimes called the hollow cathode effect, within the hole 20 is avoided. If glow reinforcement should occur within the hole 20, it would thereby become a hot spot which would prevent the workpieces from seeing the same temperature in all directions and would defeat any attempt to surround the workpieces with a uniform temperature. This condition would be aggravated by the use of a long hole in a thick wall which hole would provide a greater area for glow reinforcement.

The auxiliary anode illustrated in FIG. 2 is at a temperature T4 depending primarily upon radiation losses from container 18 (since the anode receives little or no temperature increase due to the action of the glow). The outer vacuum dome 1 will be at a temperature slightly elevated above room temperature, primarily due to radiation losses from the auxiliary anode which is heated by container 18 as explained above.

By way of example, the members 15, 16, 17 might be at a temperature of 1000 °F., container 18 at a temperature of 1000 °F. plus or minus a few tenths of a degree, and the wall of chamber 1 would be on the order of room temperature plus 100 °F. The addition of container 18 and the fact that the glow covers its inside and outside surfaces might at first be thought to substantially increase the energy required in the process. This is not so, however, since most of the energy required is to compensate for radiation losses. Since the container is merely "substituted" for the group of workpieces in so far as its relation to the outside surroundings is concerned, the radiation losses are no greater than before and, for some configurations, they might be less than if there were no container 18.

Although the arrangement shown in FIG. 1 has been highly satisfactory, FIGS. 3 through 7 illustrate suitable modifications of the invention operating on the same principle.

In FIG. 3, the vacuum chamber is shown as 21, power supply 22, gas supply 23, with electrode 24 leading into the vacuum chamber through gas-tight insulator 25. Electrically connected to the cathode 24, as before, is a container 26 containing workpieces 27. Instead of allowing the glow current to enter container 26 through a hole,
however, an auxiliary anode 28, preferably a thin circular disk, is disposed inside container 26. This is preferably accomplished by a lead 29 connected electrically to the top of the anodic vacuum chamber 21 and passing through a hole 30 in the removable lid 30 of container 26.

In the arrangement of FIG. 3, the glow will again occur on the inside surface of the container, as well as the surfaces of workpieces 27. The inner surface of container 26 will be at the same temperature as parts 27, as before. The anode 28, which would otherwise be "cold" is heated by radiation from above and below to assume substantially the same temperature as the parts to of container 26, and hence to provide in this case a "hot" anode.

Reference to FIG. 4 illustrates another modification of the invention. Here, the arrangement is similar to that in FIG. 1, except that instead of having an auxiliary anode cylinder surrounding a container 26, the walls of the vacuum chamber 21 serve as the only anode. Here, the container 26 is provided with suitable holes 31 selected in accordance with the same criteria as discussed in connection with FIG. 1. The holes must not be made so large as to allow substantial radiation losses therefrom to the relatively cold walls of vacuum chamber 21. Hence, the arrangement is somewhat less satisfactory for attaining uniform temperature than the arrangement shown in FIG. 1 where the cylindrical auxiliary anode serves to block some of this radiation loss, being at an intermediate temperature. However, the arrangement of FIG. 4 is less expensive and may be suitable in some cases where very precise temperature control is unnecessary.

FIGS. 5 and 6 illustrate yet another modification of the invention, FIG. 6 being a cross-section taken along lines VI—VI of FIG. 5. The workpiece container 33 is made by bending a sheet of metal with an increasing radius so that the walls overlap and are spaced from one another to provide a vertical gap 34 for access of ions to the interior as before. Since radiation from the workpieces is along straight lines, the workpieces will all "see" the same temperature as long as they are placed out of direct line of the gap 34, i.e., above and to the right of line 35. Of course, the container 33 is connected to the cathode as before and is provided with a cover 36 for inserting the parts to be treated.

FIG. 7 is a modification illustrating the use of a variable size opening. A container 40 has a cover 41 with an opening 42. The opening is shielded against radiation losses by a disk 43 which is arranged to be movable over a variable area of the opening. In order to accomplish this variation, the disk 43 is attached to a rod 44 operated by an outside handle 45. A suitable gland seal 46 prevents leakage. Additional fixed holes 47 may be employed in conjunction with the variable opening 42. The foregoing arrangement may be used to reduce the glow energy on the workpieces during the initial processing and then the disk 43 may be used to increase the opening after the parts are at an increased temperature.

Thus it will be seen that the invention provides means to treat plurality of workpieces in a glow discharge without particular regard to size, shape and disposition of the parts. They are simply placed in the cathodic container at random, which completely surrounds them from a radiation standpoint except for suitable means to induce the glow discharge inside the container regardless of the position of the workpieces. In the arrangement of FIG. 3, the glow is in a more direct line with the anode than are the workpieces. Hence, in the event of an arc, it has been found that the arc is more likely to occur on the surface of the container than on the surfaces of the workpieces, thereby protecting them from damage.

Modifications other than those disclosed will become apparent to those skilled in the art, and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of this invention.

What is claimed and desired to be secured by Letters Patent of the United States is:

1. In a glow discharge apparatus having outer metallic walls forming a gas-tight chamber and an insulated cathode extending into the chamber through a gas-tight insulated connection, said apparatus having a plurality of workpieces therein connected to said cathode for the purpose of treating the same in a glow discharge at uniform temperature, the combination of:
   a. a hollow electrically conductive container disposed in said chamber and electrically connected to said cathode, said container having walls surrounding said workpieces and provided with a removable cover for the insertion of said workpieces therein, and
   b. means for inducing a glow on the interior walls of the container as well as on the surfaces of the workpieces therein, said means including at least one opening through the container wall large enough to preclude glow reinforcement within said opening as well as to admit the glow inducing means so as to act on the interior walls and the workpieces but yet arranged to prevent substantial radiation loss from the workpieces to the outside of the container through said opening.

2. The combination according to claim 1 wherein an auxiliary anode is disposed in said chamber and surrounds said container so as to reduce radiation loss through said opening.

3. The combination according to claim 1 wherein an auxiliary anode is disposed in said chamber, and which also extends into the interior of said container by a lead passing through said opening.

4. The combination according to claim 1 including means for varying the size of said opening while the glow discharge is taking place.

5. The combination according to claim 1 wherein said container comprises a substantially cylindrical sidewall member electrically connected to said cathode along with the workpieces, said member having said opening arranged along the cylindrical sidewall.

6. The combination according to claim 1 wherein said opening is a gap defined by overlapping and spaced wall portions of said cylindrical sidewall member.

7. The combination according to claim 5 wherein said opening is a gap defined by overlapping and spaced wall portions of said cylindrical sidewall member.

8. Glow discharge apparatus for nitriding a plurality of workpieces of nonuniform size, shape or disposition at uniform temperature comprising:
   a. an outer vessel having metallic walls providing a gas-tight chamber with an insulated cathode extending into the chamber through a gas-tight connection, a source of electrical power for connecting the outer vessel as the anode and connected to said cathode for providing a glow discharge in said chamber, means for providing a low pressure nitrogenous atmosphere in said chamber,
   b. a hollow electrically conductive container disposed in said chamber and electrically connected to said cathode, said container having a removable cover for insertion of the workpieces and having walls surrounding the workpieces, and
   c. means for inducing a glow on the interior walls of the container as well as on the surfaces of the workpieces therein, said means including at least one opening in the container wall large enough to admit the glow inducing means to the interior of the container.
and to prevent glow reinforcement within said opening, but arranged with respect to the workpieces to substantially impede radiation loss therefrom to the outside of the container through said opening.

9. A process for treating a plurality of workpieces of non-uniform size, shape or disposition at uniform temperature in a glow discharge comprising:

- providing an electrically conductive hollow container having at least one opening in the walls thereof,
- dimensioning said opening to provide a passage large enough to preclude glow reinforcement and to admit a glow inducing means, connecting both workpieces and container as the cathode,
- arranging said pieces inside the container so that radiation losses therefrom through said opening will be negligible, and
- inducing a glow to take place on the interior of the container and on the workpieces through said opening.

10. The process according to claim 9 including the additional step of varying the size of said opening while the glow is taking place.

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