March 21, 1939. R. C. WILLIAMS 2,151,457

METHOD OF COATING SURFACES BY THERMAL EVAPORATION

Filed July 14, 1936 2 Sheets-Sheet 1

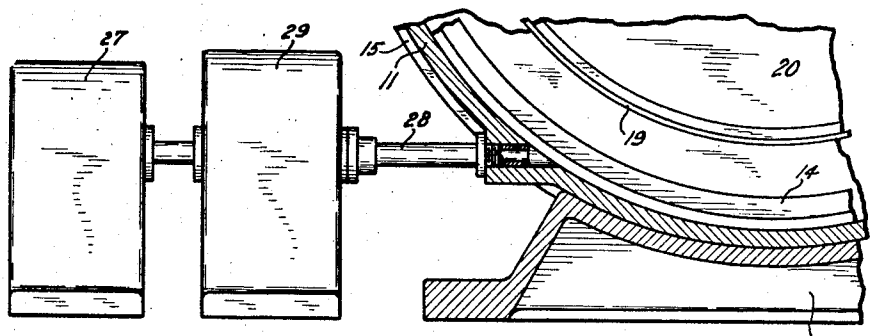


Fig. 3

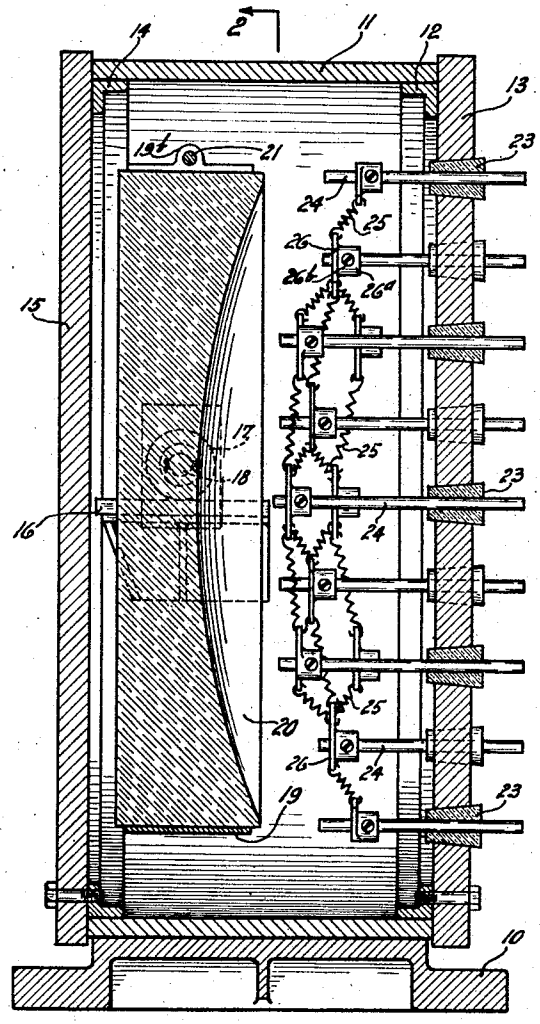


Fig. 1

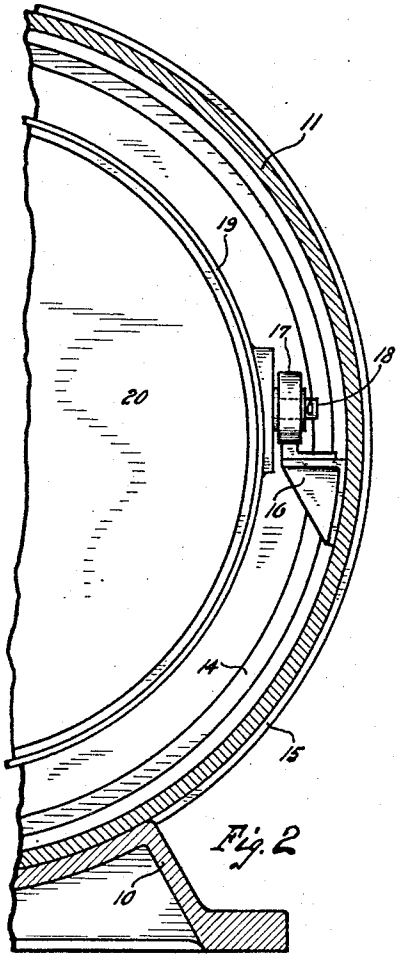


Fig. 2

INVENTOR.
ROBLEY C. WILLIAMS

BY Lewis Hudson & Kent
ATTORNEYS

March 21, 1939. R. C. WILLIAMS 2,151,457

METHOD OF COATING SURFACES BY THERMAL EVAPORATION

Filed July 14, 1936 2 Sheets-Sheet 2

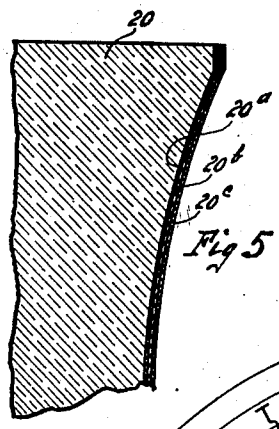


Fig. 5

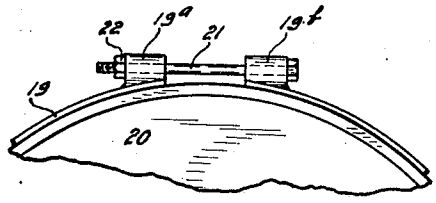


Fig. 4

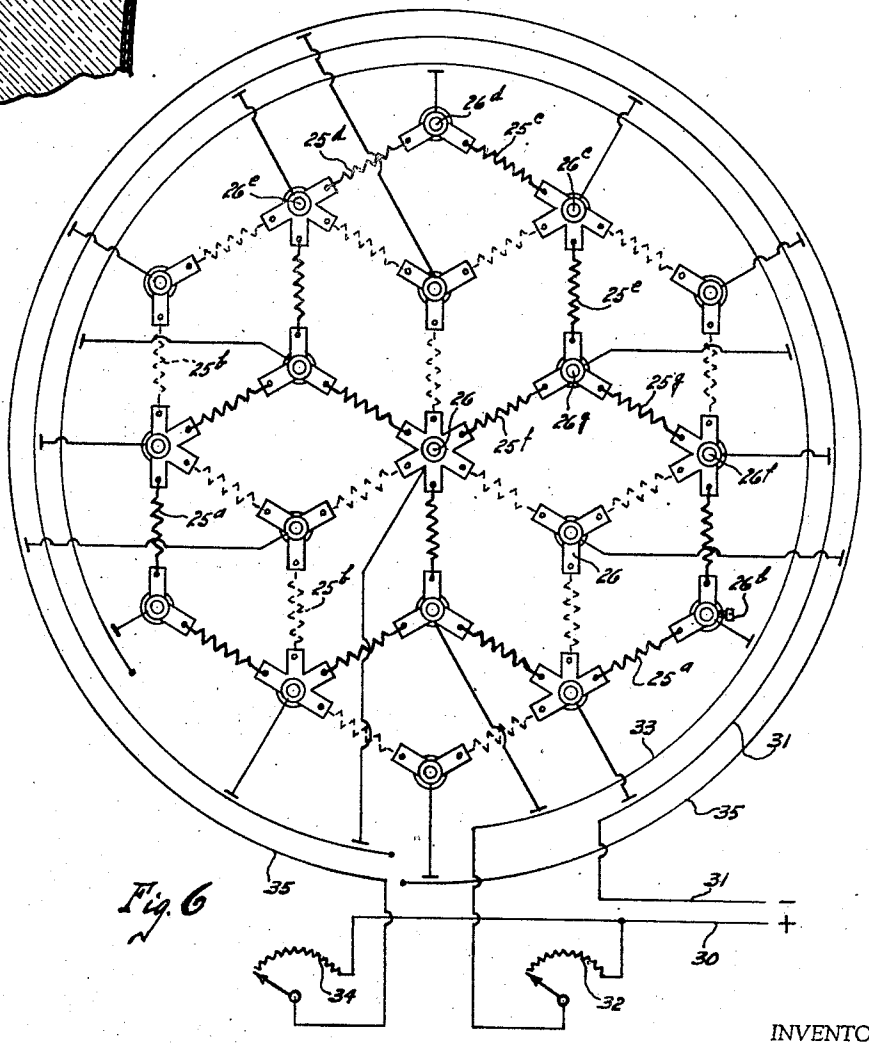


Fig. 6

INVENTOR.

BY ROBLEY C. WILLIAMS

Kuris Hudson & Kent

ATTORNEYS

Patented Mar. 21, 1939

2,151,457

UNITED STATES PATENT OFFICE

2,151,457

METHOD OF COATING SURFACES BY THERMAL EVAPORATION

Robley C. Williams, Ann Arbor, Mich.

Application July 14, 1936, Serial No. 90,517

16 Claims. (Cl. 91—70.1)

This invention relates to a method of coating surfaces by thermal evaporation.

This application is in part a division of my application Serial Number 652,529, filed January 19, 1933, for Plating by thermal evaporation.

An object of the invention is to provide an improved method of coating surfaces by means of thermal evaporation in a vacuum.

Another object is to provide a method of coating surfaces, such as mirrors and similar articles, whereby the coatings will possess the desired attributes of reflectivity, tenacity, hardness and durability.

A further object is to provide a method of coating surfaces whereby the coatings may be formed by the evaporation of a plurality of different coating materials simultaneously or successively in a single vacuum.

Another object is to provide a method of forming a coating on a surface by thermal evaporation in a single vacuum, and wherein the coating will consist of a layer of one material gradually grading off into an alloy of the first material with a second material, and then with the alloy gradually grading off into a layer of the second material.

A still further object is to provide a method of coating the surface of a mirror or other article by thermal evaporation in a single vacuum with a coating formed of chromium, graded off into a chromium aluminum alloy, which, in turn, is graded off into a coating of aluminum.

Further and additional objects and advantages not expressly set forth above will appear hereinafter during the detailed description which is to follow.

The method of the present invention may be employed for coating many different kinds of articles, but it has particular utility in connection with the coating of mirrors and other reflecting surfaces for use in astronomical and scientific instruments.

In astronomy and in experimental and demonstrative physics much apparatus is used in which light is reflected for various purposes. Mirror surfaces are necessary to reflect light in a definite manner and where a high degree of accuracy and efficiency of reflection is demanded it can be best obtained with front surface mirrors having a coating thereon of high reflecting power, uniformly distributed over the surface.

Among the specific articles, instruments or apparatus which may have the surfaces or parts thereof advantageously coated by the present method are telescope mirrors, searchlight reflectors, spectrohelioscopes, electrometer suspensions, interferometer plates, ruled gratings, prisms of Littrow spectographs and other instruments where a reflecting surface with unchanging characteristics is required.

In order to explain in detail the method of the present invention reference will be made herein by way of example to the coating of a front surface telescope mirror.

Referring to the accompanying drawings showing one form of apparatus for carrying out the method,

Fig. 1 is a sectional view through the center of an apparatus similar to the apparatus shown in Figs. 8, 9 and 10 of the hereinbefore mentioned application Serial Number 652,529.

Fig. 2 is a fragmentary sectional view taken on line 2—2 of Fig. 1, looking in the direction of the arrows.

Fig. 3 is a fragmentary sectional view also taken along line 2—2 of Fig. 1 but showing another portion of the apparatus and illustrating the pumps for evacuating the chamber.

Fig. 4 is a fragmentary view illustrating the manner in which a supporting strap is clamped to the mirror.

Fig. 5 is a fragmentary sectional view of the mirror as viewed in Fig. 1 on an enlarged scale, and illustrates in an exaggerated way the formation of the coating applied to the front surface of the mirror.

Fig. 6 is a diagrammatic view of the filaments employed in the apparatus shown in Fig. 1, together with a diagram of the electrical circuits and controls therefor.

The method comprises as the first step thereof the cleansing of the surface to be coated. This is a very important step in the coating of surfaces of different objects by thermal evaporation in a vacuum, and it is most important that the surfaces should be free of any film of grease or other foreign matter, and also that the surfaces should be thoroughly and completely dried. Heretofore, it has been difficult to treat the surface so that it is both clean and dry. It has been found that an effective way of cleansing the surface and also getting it into a thoroughly dry state, is to first treat the surface with a suitable detergent, such as dilute caustic potash (KOH), sodium hydroxide (NaOH), or other detergent after which it is rinsed and then treated with concentrated nitric acid. Following the nitric acid treatment the surface is thoroughly rinsed with water, and the article is preferably positioned so that the water may drain off as well as possible.

When the water has drained off as much as it will the surface is carefully rinsed with as good a grade of absolute ethyl alcohol as is obtainable in order to thoroughly cleanse the surface. It has been found that when ethyl alcohol is employed which is substantially absolute ethyl, no film will be left on the surface and the coating will effectively adhere to the surface and will not deteriorate more rapidly with the passage of time. The alcohol rinse acts to remove the relatively slow drying water, which by itself will not evaporate quickly enough or cleanly enough. Then a gentle current of hot, dry, filtered and clean air is blown over the surface to quickly dry the alcohol. After the surface has been cleansed and the filaments have been so adjusted and arranged that the material evaporated therefrom will effect a uniform distribution of the coating film upon the surface, the article is placed in the vacuum chamber, the chamber sealed, and the evacuation of the chamber started.

When the chamber has been evacuated to a degree that will later be referred to, the electrical circuits through the filaments are closed in order to heat the filaments and cause an evaporation of the coating material or materials therefrom to create in the chamber a vapor of the material which will condense as a film upon the surface to be coated. If a coating of a single material is to be applied to the surface to be coated all of the filaments have deposited or arranged thereon a quantity of the coating material, and said filaments may be heated either singly, in groups, or all simultaneously to effect an evaporation or distillation of the coating material therefrom. If the coating is to be formed of more than one material the filaments will be arranged in groups, with the filaments of certain groups provided with one of the coating materials and the filaments of each of the other groups provided respectively with other of the coating materials. If it is desired that the coating be in the form of an alloy of all of the materials, then the different groups of filaments can be heated simultaneously to distil the materials therefrom, and cause the intermingled vapors of all the materials to condense on the surface. If the multi-material coating is to be formed with distinct layers of different materials, then the different groups of filaments are successively heated, to successively deposit upon the surface to be coated films of the different materials. In other instances it is desirable for the coating to be formed of two or more different materials, with a gradually graded alloy of the different materials between the layers of such materials. In these instances the filaments containing the first material to be deposited upon the surface to be coated are heated for a predetermined length of time, at their maximum evaporation heat, and then the current is slowly reduced and they are allowed to gradually cool, during which cooling period the filaments containing another material are gradually heated so that the film of the first material grades into an alloy of the first and second materials, with the first material content of the alloy gradually decreasing and the second material content thereof gradually increasing until the alloy merges into a film of the second material. As previously stated, this is accomplished by gradually cooling the first group of filaments and gradually increasing the heat of the second group of filaments until the first group has cooled sufficiently so that no material is evaporated therefrom, while the second group has reached a temperature at which maximum evaporation takes place.

The filaments for definite periods of time are heated at certain predetermined temperatures, dependent upon the thickness of the coating to be applied to the surface and the nature of the material to be evaporated.

After the coating has been deposited upon the surface of the article air may be admitted to the chamber and the article removed therefrom. Although further treatments of the coating are not necessary insofar as reflectivity is concerned, it is advisable and desirable to harden the coating to make it durable and to prevent the same from being scratched or otherwise injured. The hardening of the coating is effected by subjecting the coating to moisture, and then gently rubbing off the moisture with a soft cloth of cotton or other suitable material.

The hardening of the coating commercially can very advantageously be carried out by rinsing the surface thereof with water or alcohol, and as the washing or rinsing of the surface of the coating proceeds and the surface feels smoother, the pressure applied to the cotton or other rubbing agent can be gradually increased. It is believed that the washing of the coating effects what is essentially a burnishing thereof, in that the particles making up the deposited coating or surface originally were arranged at random while the washing and rubbing of the surface flattened these particles down, smoothing the surface and making the same denser.

The foregoing broad description of the steps of the method has not referred to any particular coating materials, since a wide variety of materials might be employed according to the characteristics desired for particular coatings. It has been found that combination coatings may be more preferable than single coatings, in that the desirable characteristics of more than one material can be combined. A coating of considerable advantage to astronomers and physicists in connection with front surface mirrors is the combination coating of chromium and aluminum. The relatively hard chromium adheres very strongly to the glass or metal undersurface and furnishes an excellent base for the relatively softer aluminum which possesses a greater degree of reflectivity. A coating of aluminum alone is subject to attack by any alkalies present in the atmosphere, and will in time deteriorate if such alkalies contact with the coating. This deterioration may continue until the aluminum is completely removed from the surface. I have found that in the case, however, of a combination coating formed of chromium, chromium-aluminum alloy and aluminum the deterioration of the aluminum from alkalies will proceed only to the point where the chromium in the alloy is enough to stop such deterioration. The reflectivity of the alloy at this point is only slightly less than that of pure aluminum, and considerably more than that of chromium, so that such a combination film possesses the advantage of chemical durability as well as high reflectivity.

A combination coating of this character possesses the further advantage that it is mechanically durable, and even rubbing or scratching will not penetrate the relatively hard chromium undercoat. A combination coating of chromium, chromium-aluminum alloy and aluminum, as mentioned above, since it combines the desirable attributes of both metals, results in the production of a coating which is substantially permanent

in use, has a high degree of reflectivity and need not be renewed from time to time, as would be the case if only an aluminum coating were employed.

It has been found desirable to employ in methods based upon thermal evaporation in a vacuum an underlayer of chromium in the coating, in combination with any metal whose tenacity in the thin film form is not great, inasmuch as the layer of chromium which possesses the necessary tenacity will maintain the thin film or layer of the other metal in position upon the surface. Combination coatings such as have been referred to will only produce the advantageous results if the different materials of the coatings are evaporated from the filaments and deposited upon the surface to be coated in one and the same vacuum. It has been found that if air is admitted after the chromium film or coat is applied, the latter will become covered with an oxide coating, to which the other material, such as aluminum for example, will not be particularly adherent. Hence it is important in the production of combination films that such films be deposited upon the surface to be coated in one and the same vacuum.

As an example of an advantage residing in the use of a combination coating, such as a coating of chromium and aluminum, reference is made to the fact that the present method has been employed in the production of diffraction gratings containing from 15,000 to 30,000 lines per inch. When the gratings are coated with a layer of aluminum over a layer of chromium the lines of the grating can be cut in the soft aluminum by means of a lightly loaded diamond point, but the diamond point will not cut into the relatively hard chromium. The chromium will give the aluminum sufficient tenacity and is not stripped away from the glass by the action of the point in drawing lines upon the grating. On the other hand a coating of pure aluminum would not have adequate tenacity, and such coating would be stripped from the glass when the lines were made therein. Likewise, a coating of chromium alone would not be suitable, since its hardness would render the drawing of the lines in the coating very difficult.

In addition to the use of chromium as an undercoating other materials or metals having the characteristic of tenacity might also be employed, as, for example, it has been found that an undercoating of beryllium produces many of the advantageous features of the undercoating of chromium.

In order to better explain the method of the present invention, reference will now be made to a specific instance of coating a front surface telescope mirror and to the manner in which a particular apparatus constructed to carry out the method is employed.

The apparatus comprises an enclosure forming the coating chamber, and said enclosure or chamber as illustrated herein is substantially cylindrical in shape. The enclosure comprises a foot or base 10 which is secured to and supports a cylinder 11 formed of a suitable material, such as plate steel, which can readily be machined so that the inner surface of the cylinder will be perfectly smooth. The interior of the cylinder 11 adjacent one of its ends (the right hand as viewed in Fig. 1) is provided with a cylindrical angle iron 12, welded to the cylinder and acting as a shoulder against which an end plate 13 can be bolted, it being understood that a suitable seal is provided between the end plate 13 and the cylinder 11. The opposite end of the cylinder 11 is also provided with an angle iron 14 similar to the angle iron 12 and against which a removable end plate 15 is bolted and which plate is sealed with respect to the cylinder as will be well understood.

At diametrically opposite points on the interior of the cylinder 11 and adjacent to the left hand end of the cylinder, as viewed in the drawings, supporting rails 16 are welded to the interior of the cylinder, and said rails act as a support for rollers 17 mounted on bearing pins 18 carried by reenforcements connected to a strap 19 which surrounds the mirror 20, and is secured in position upon the mirror by means of a bolt 21 passing through lugs 19a and 19b formed on the adjacent spaced ends of the strap, a nut 22 threaded on said bolt acting to hold the strap in position on the mirror. It will be seen when the plate 15 is removed from the cylinder the mirror 20 may be rolled from a supporting truck onto the supporting rails 16 and thus properly positioned within the cylinder or chamber.

The plate 13 is provided with a plurality of tapered openings which receive tapered plugs 23 formed of insulated material, and said plugs carry or support electrically conductive rods 24, the rods being sealed in the plugs and certain of the rods being of longer length than other of the rods for a purpose later to be explained.

The filaments which are to be heated to evaporate the coating material or materials have deposited or otherwise arranged thereon said coating materials and are indicated in Fig. 1 at 25, and these filaments are supported by spiders 26, each of which is provided with a collar 26a, whereby the spiders can be adjusted inwardly and outwardly upon the rods 24 and clamped in position thereon by means of suitable clamping screws 26b. The purpose of using different length rods 24 and of having the spiders 26 adjustable on the rods is to enable the filaments to be located all at the same distance from the concave front surface of the mirror 20 so as to obtain an equal distribution or disposition upon the concave surface of the mirror of the vaporized material forming the coating. This arrangement is very important in the coating of mirrors, irrespective of the size and shape of the mirror, but is particularly important in connection with large size front concaved surface telescope mirrors, wherein the coating must be of equal thickness throughout the entire coated area to maintain the accuracy of the polished mirror surface for correct and accurate reflectivity.

In order to properly evacuate the chamber or cylinder a primary vacuum pump 27 connected to the chamber by a conduit 28 is used to withdraw the greater portion of the air from the chamber, while a secondary pump 29 also connected to the conduit 28 is employed to reduce the pressure of the air in the chamber to less than 0.0001 mm. of mercury.

In Fig. 6 there is illustrated diagrammatically an arrangement of the filaments, in this instance there being two groups of filaments, in one of which the filaments are provided with chromium and in the other of which the filaments are provided with aluminum, the chromium filaments being indicated by full lines and the aluminum filaments being indicated by dash lines. Fig. 6 also shows diagrammatically the wiring or electrical circuits for heating the filaments, together with rheostats for controlling the heat of said filaments.

The full line chromium filaments are indicated

by the reference character 25a, while the dash line aluminum filaments are indicated by the numeral 25b. It will be noted that the filaments are disposed or located in such manner that each filament is allotted a predetermined area of the surface to be coated, and that all of the filaments combined will cover the entire area of the surface, wherefore the coating will have a substantially equal thickness throughout its area.

The filaments and electrical circuits are so arranged that one filament only at a time may be heated or the filaments may be heated in groups of two or three or more at a time, or all or some of the chromium filaments may be heated at a time, or all or some of the aluminum filaments may be heated at a time, or all or some of both the chromium and aluminum filaments may be simultaneously heated. In the last instance the deposit upon the surface to be coated would be in the nature of chromium-aluminum alloy, with the percentages of the constituent ingredients of the alloy proportional to the number of filaments of each metal being heated and the degree of heat imparted to said filaments.

The electrical conduit 30 and the electrical conduit 31 represent, respectively, the positive and negative sides of a source of electrical energy. The positive conduit 30 is connected through a rheostat 32 with a conduit 33 which can be connected to the rods 24 supporting the spiders carrying the filaments. The conduit 30 is also connected through a second rheostat 34 to a conduit 35 which likewise can be connected to the rods 24 supporting the filaments. The negative conduit 31 is here illustrated between the conduits 33 and 35, and this negative conduit can be selectively connected to one or more of the rods 24, whereby the circuit can be completed through the filaments individually or in groups or all simultaneously as previously referred to. The rheostat 32 will control the circuits through the chromium filaments, while the rheostat 34 will control the circuits through the aluminum filaments to thus vary the degree of heat of the filaments and the speed and amount of vaporization of the coating metals therefrom.

It will be seen from an inspection of Fig. 6 that certain of the posts can be connected to the negative circuit while other of the posts can only be connected to the positive circuits, as will be observed from the diagrammatic lead lines extending from the posts to the negative conduit 31 and those extending from the posts to the positive conduits 33 and 35.

It will be seen by reference to Fig. 6 that when the lead or wire from the post indicated at 26c is connected to the negative conduit 31 and the lead from the post indicated at 26d is connected to the positive conduit 33 then only the full line chromium filament indicated at 25c will be energized or heated and the degree of heat in said filament can be regulated by the rheostat 32. If the chromium filament indicated at 25d is to be heated in addition then the lead from the post indicated at 26e is connected to the negative conduit 31, at which time both filaments 25c and 25d are in the circuit and will be heated. If, however, only the filament 25d is to be heated then the lead from the post 26c to the negative conduit is disconnected. If some of the filaments are to be heated in groups of three as, for example, the chromium filaments indicated at 25e, 25f and 25g, then there will be three ground connections to the negative conduit 31, as indicated by the leads from the posts 26c, 26 and 26f and one positive connection as indicated by the lead from the post 26g. If all of the chromium filaments are to be heated simultaneously then all of the negative connections and all of the positive connections from the posts which support the chromium filaments are to be made. In the same way the aluminum filaments indicated by the dash lines can be heated singly, or in groups of two or three, or all simultaneously. Likewise, by making the suitable connections to the positive and negative conduits some of both the chromium and aluminum filaments can be simultaneously heated, or all of the chromium and aluminum filaments can be simultaneously heated, and in any arrangement of filament heating the degree of heat effected in the different groups can be controlled by the rheostats 32 and 34 respectively.

The method will now be described with special reference to the coating of the front surface of the telescope mirror 20, so as to provide on said surface a coating of chromium, chromium-aluminum alloy and aluminum. The interior of the cylinder and the inner surfaces of the end plates, as has been previously stated, are machined so that there will be no depressions or holes in which water or other matter can be confined which would produce objectionable gases when the chamber is evacuated.

Assuming that the chamber is in proper condition, the filaments are arranged and mounted in accordance with the size of the surface to be coated and the curvature or configuration of such surface, it being remembered that the filaments when the surface is concave or non-planular in form will be located so that all of the filaments will be an equal distance from such surface. The front surface of the mirror is now cleaned by subjecting it to a treatment of dilute caustic potash, or other suitable detergent after which the surface is rinsed and treated with concentrated nitric acid. After the nitric acid treatment the mirror is thoroughly rinsed with water and this water is allowed to drain off as much as possible. Then the surface is carefully rinsed with as nearly absolute ethyl alcohol as is obtainable and then a current of hot, filtered, dry air is blown over the alcohol on the surface to effect a very quick drying thereof. The mirror is now mounted in the strap and by means of the rollers 17 and supporting tracks 16 correctly positioned in the chamber, the plate 15 is then secured to the chamber and a sealing relationship effected between the plate and the chamber, after which the chamber is properly evacuated by the pumps 27 and 29. As soon as the chamber has been evacuated to the proper amount, that is to 0.0001 mm. of mercury, the circuits through the filaments may be closed and the filaments heated as will now be explained. First, all of the chromium filaments are heated to a maximum evaporation heat and for a predetermined length of time to distil or evaporate the chromium therefrom and which will condense upon the front surface of the mirror in a coating layer of chromium, as indicated at 20a in Fig. 5. Then by means of the rheostats 32 and 34 the current through the chromium filaments is gradually reduced and the current through the aluminum filaments is turned on and gradually increased at the same time to effect a deceleration in the heat and the evaporation of the chromium filaments, and an acceleration in the heat and evaporation of the aluminum filaments. This results in a combined film of chromium and aluminum

being condensed as an alloy on the chromium coating previously condensed upon the surface of the mirror, and this alloy will be gradually shaded with respect to percentages of chromium and aluminum from an alloy having a dominant percentage of chromium to an alloy having a dominant percentage of aluminum. The alloy layer of the coating is indicated in Fig. 5 at 20b. The reduction of the current through the chromium filaments and the increase of the current through the aluminum filaments is carried on until the current through the chromium filaments is sufficiently reduced to allow said filaments to cool below vaporization heat, while the maximum current through the aluminum filaments is reached. From this time on only aluminum will be evaporated and hence a layer of pure aluminum, as indicated at 20c, is deposited upon the chromium aluminum alloy layer 20b.

It will be understood, however, that although the layers 20a, 20b and 20c are illustrated in Fig. 5 as distinct and separate layers, that said layers will gradually merge from a layer of pure chromium into a layer of chromium-aluminum alloy, and then merge into a layer of pure aluminum.

If necessary suitable ammeters might be provided in the circuit to indicate the intensity of the current passing through the chromium and aluminum filaments, in order to assist the operator in determining the degree of evaporation taking place throughout the operation.

As soon as the evaporation of the filaments has been completed the plate 15 is removed and the mirror is rolled out of the chamber. The front or coated surface of the mirror is now hardened and made more durable by rinsing such surface with water or alcohol and very gently rubbing off the moisture with soft cotton or other suitable rubbing agent and gradually increasing the pressure of the rubbing action as the surface becomes smoother, such rubbing of the surface acting to burnish the same and smooth out the minute particles of the coating.

The description of the method heretofore given herein will indicate that coatings can be formed thereby on the surfaces of various articles in an expeditious and efficient manner and under the control of the operator at all times and in such way as to meet the conditions incident to various forms of coatings. It has been found from long experience that one of the most important steps in the application of coatings to surfaces of articles is the thorough cleaning and drying of the surface prior to placing the article in the vacuum for the deposit of the coating thereon, and that if the surface is not thoroughly cleaned and dried the coating will not properly adhere thereto.

It will be noted that the present method adequately provides for the thorough cleansing and drying of the surface of the article prior to the deposition of the coating thereon, and thus assures the desired tenacity of the coating with respect to the surface. The method further enables the coating to be formed in the same vacuum and with any desired combination of metals or alloys whereby various combinations can be selected to suit different conditions as, for example, the combination of chromium, chromium-aluminum alloy and aluminum coating wherein the chromium provides tenacity, the aluminum, reflectivity, and the chromium-aluminum alloy the resistance against deterioration by alkalies, while at the same time possessing substantially the reflectivity of pure aluminum.

It will further be observed that the method included as a final step thereof the burnishing of the surface by washing and rubbing the same, and that this step is of great importance, inasmuch as it hardens, smooths out and condenses the fine particles of the coating, thus imparting durability and long life to the coating.

The description of the method hereinbefore set forth is by way of illustration, and it will be understood that variations may be made therein from the specific details referred to herein and which come within the scope of the appended claims.

Having thus described my invention, I claim:

1. The method of coating the surface of an article which comprises placing the article in a chamber, producing a substantial vacuum in said chamber, and then by means of thermal evaporation successively depositing on said surface and in the same vacuum a coating formed of a plurality of layers of different metallic materials.

2. The method of coating a surface of an article which comprises placing the article in a chamber, forming a substantial vacuum within the chamber, and then by means of thermal evaporation depositing on said surface and in the same vacuum coatings of two different metallic materials separated by a coating of an alloy of said two metallic materials.

3. The method of coating a surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in said chamber, and then while the article is in the same vacuum evaporating one metallic material to form a layer thereof upon the surface, gradually reducing the evaporation of said metallic material while at the same time commencing and gradually increasing the evaporation of another metallic material to form a layer of a graded alloy of the two materials upon the layer of the first material and then evaporating only the second material to provide a layer thereof upon the alloy layer.

4. The method of coating a surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in said chamber, and then while the article is in the same vacuum evaporating simultaneously a plurality of different metallic materials and controlling the rates of evaporation of the different materials to provide upon the surface a coating formed of an alloy of said materials and having at different points therein intermediate its inner and outer surfaces variable percentages of said materials.

5. The method of coating a surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in the chamber, and then by thermal evaporation successively depositing upon the surface in the same vacuum a coating of chromium and a coating of aluminum.

6. The method of forming a coating upon the surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in said chamber, and then by means of thermal evaporation depositing upon the surface in the same vacuum a coating formed of chromium, chromium-aluminum alloy and aluminum.

7. The method of forming a coating upon the surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in said chamber, and then in the same vacuum evaporating chromium to form a chromium layer upon the surface, gradually reducing the evaporation of the chromium while at the same time commencing and gradually in-

creasing the evaporation of aluminum to form a chromium-aluminum alloy upon the chromium layer, and then evaporating only aluminum to provide an aluminum layer upon the alloy layer.

8. The method of forming a coating upon the surface of an article which comprises placing the article in a chamber, forming a vacuum in said chamber, and then while in the same vacuum and by means of thermal evaporation evaporating one metallic material in a gradually diminishing amount and another metallic material in a gradually increasing amount to form a graded alloy coating upon the surface.

9. The method of forming a metallic coating upon the surface of an article, which comprises first cleaning the surface by subjecting the said surface to a treatment with dilute caustic potash followed by rising and a treatment with concentrated nitric acid, then rinsing with water, treating the surface with ethyl alcohol, drying said surface, then placing the article in a chamber, forming a vacuum in said chamber, then by means of thermal evaporation while in the vacuum depositing the metallic coating upon said surface, removing the article from the chamber and then burnishing the coating by rinsing the same with liquid, and then rubbing off the liquid and gradually increasing the pressure of the rubbing action until the surface is smooth and hard.

10. The method of coating the surface of an article which comprises cleansing said surface by subjecting the same to a treatment of dilute caustic potash, rinsing the surface, treating it with concentrated nitric acid, rinsing with water, applying ethyl alcohol thereto, then drying said surface, placing the article in a chamber, forming a substantial vacuum in said chamber and then by means of thermal evaporation in the same vacuum successively applying coatings of chromium and aluminum to the surface, removing the article from the chamber, and then burnishing the coating by subjecting the surface thereof to a treatment with a liquid followed by a rubbing action, and gradually increasing the intensity of the rubbing action until said coating is hard and smooth.

11. The method of coating the surface of an article which comprises cleansing said surface by subjecting the same to a treatment of dilute caustic potash, rinsing the surface, treating it with concentrated nitric acid, rinsing with water, applying ethyl alcohol thereto, then drying said surface, placing the article in a chamber, forming a substantial vacuum in said chamber and then by means of thermal evaporation in the same vacuum successively applying coatings of chromium, chromium-aluminum alloy and aluminum to the surface, removing the article from the chamber, and then burnishing the coating by subjecting the surface thereof to a treatment with a liquid followed by a rubbing action, and gradually increasing the intensity of the rubbing action until said coating is hard and smooth.

12. The method of coating a surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in said chamber, and then by thermal evaporation successively depositing upon said surface while in the same vacuum a layer of a highly tenacious metallic material and then a layer of a different metallic material upon said first layer.

13. The method of coating a surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in said chamber, and then by thermal evaporation successively depositing upon said surface while in the same vacuum a layer of chromium and then a layer of a different metallic material upon said chromium layer.

14. The method of coating a surface of an article which comprises placing the article in a chamber, forming a substantial vacuum in said chamber, and then by thermal evaporation successively depositing upon said surface while in the same vacuum a layer of beryllium and then a layer of a different material upon the beryllium layer.

15. The method of coating a telescope mirror which comprises placing the mirror in a chamber, forming a substantial vacuum in said chamber, and then by thermal evaporation successively depositing upon said mirror while in the same vacuum a layer of a highly tenacious metallic material and then upon the first layer a layer of a metallic material having high reflectivity.

16. The method of forming a metallic coating upon a surface of an article which comprises treating said surface with dilute caustic potash, rinsing the surface, treating the same with concentrated nitric acid, rinsing with water, then applying absolute ethyl alcohol to said surface, then drying the surface by directing a current of heated filtered air across the same, placing the article in a vacuum, and then by means of thermal evaporation while in the vacuum depositing upon the surface a film of metallic coating material.

ROBLEY C. WILLIAMS.