

Feb. 5, 1952

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2,584,660

VACUUM COATING PROCESS AND APPARATUS THEREFOR

Filed Sept. 24, 1949

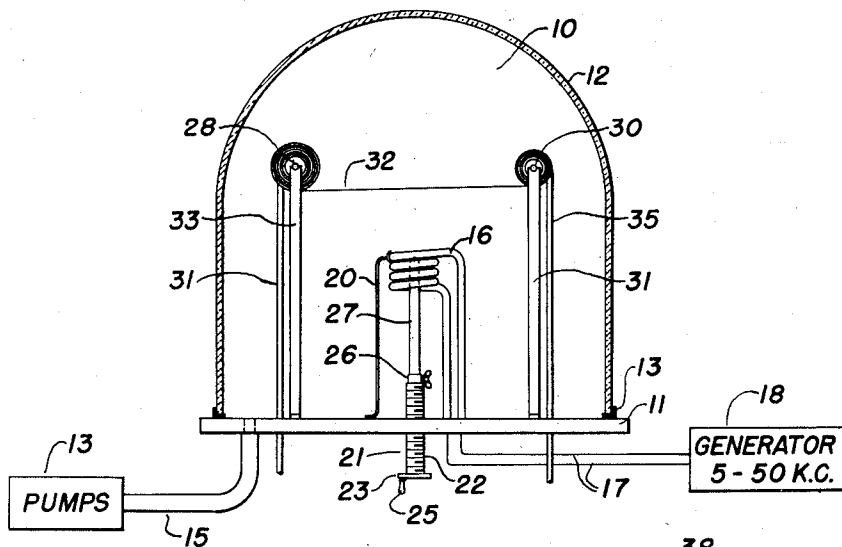


FIG. 1

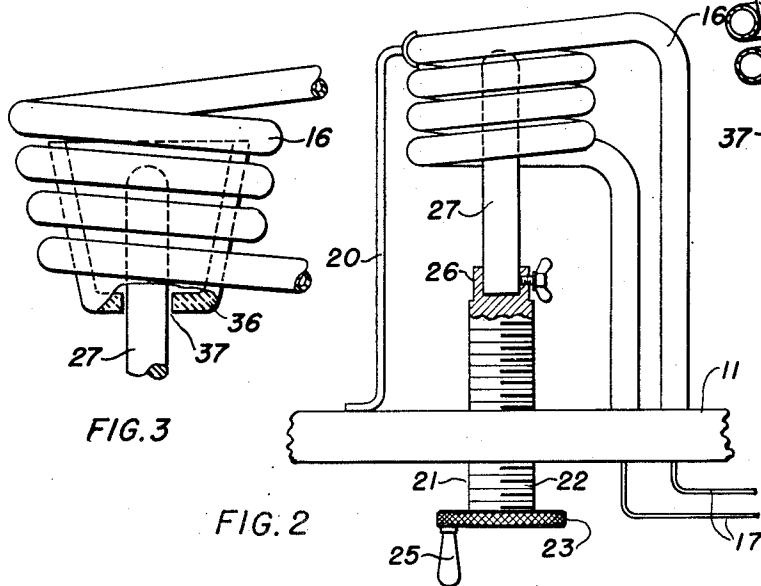


FIG. 2

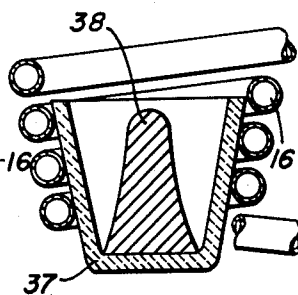


FIG. 3

FIG. 4

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2,584,660

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Application September 24, 1949, Serial No. 117,598

9 Claims. (Cl. 117-93)

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This invention relates to the art of coating materials under vacuum and is particularly concerned with coating materials with metal vapors evolved by thermal evaporation under vacuum.

It is an object of this invention to provide improved apparatus for coating materials under vacuum.

It is a further object of the invention to provide means for continuously coating strip material with metal.

It is a further object to provide metal coating apparatus not subject to breakdown during operation.

Another object of the invention is to provide means for subjecting coating metal to thermal evaporation in a progressive manner without interrupting the coating process.

Another object of the invention is to provide an improved process for thermally evaporating coating metal under vacuum.

Another object of the invention is to obviate the necessity of employing physical supporting means to laterally support molten metal being evaporated under vacuum.

Another object of the invention is to provide metal coating apparatus not subject to crucible failure.

Other objects will be apparent from the drawings, description and claims.

Of the drawings:

Fig. 1 is a view in elevation and partly in section of vacuum coating apparatus constituting a preferred embodiment of the invention;

Fig. 2 is an enlarged fragmentary view in elevation of the coater shown in Fig. 1 with particular reference to the source;

Fig. 3 is a fragmentary view in elevation of a modified source; and

Fig. 4 is a fragmentary view in elevation partly broken away and in section of a further modified source, including a crucible and a charge of metal having the configuration assumed by the metal when melted in accordance with this invention.

The invention is best understood by reference to preferred apparatus embodying the invention as shown in Fig. 1. The preferred apparatus comprises an evacuable chamber 10 formed by wall means consisting of base 11 and bell dome 12. Bell dome 12 is movable into and out of sealing engagement with base plate 11, gasket 13 providing a gas-tight seal when dome 12 is in position on base plate 11.

Chamber 10 communicates with pumping means 13 through conduit 15, pumping means 13 comprising any suitable vacuum pumping ar-

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angement for evacuating chamber 10 to a pressure below about 100 microns Hg. and preferably below 10 microns Hg. The pumping means desirably comprises a plurality of diffusion pumps backed by a mechanical pump in the manner well known in the art.

The source for thermally evaporating coating metal in chamber 10 comprises induction heating coil 16 connected by leads 17, 17 through base plate 11 to current generator 18.

Coil 16 preferably comprises a plurality of turns of copper or other metal tubing defining a central opening in which an alternating electromagnetic field is established when coil 16 is energized by generator 18. Coil 16 is rigidly supported in generally vertical position inside chamber 10 by post 20 which is mounted on base plate 11.

Generator 18 adapted to energize coil 16 is an alternating current generator supplying current having a frequency of about 5 to 50 kilocycles per second.

Extending through base plate 11 in vertical alignment with coil 16 is adjustable feed member 21 comprising a threaded shank 22 extending through a threaded opening in base plate 11, knurled head 23 and handle 25, and clamping collar 26. Collar 26 is adapted to hold and vertically support a rod 27 of coating metal with an end portion of rod 27 extending upwardly into coil 16. In the interest of simplicity, a manually operable feed has been illustrated but power driven feeds and automatic controls may be added.

Driven rolls 28 and 30 are rotatably supported in spaced relation in chamber 10 on support members 31, 31. Rolls 28 and 30 carry strip material 32 to be coated. Rolls 28 and 30 are controllably rotated by rotatable shafts 33 and 35 respectively geared with rolls 28 and 30 and extending downwardly through gland packings (not shown) in base plate 11 to suitable driving means (not shown). Rolls 28 and 30 are arranged to roll and unroll strip material 32 in proximity to the source.

In a modified form as shown in Fig. 3, the source employed in the apparatus embodying the invention comprises a refractory crucible 36 mounted in and supported by coil 16. Crucible 36 is provided with an opening 37 through the bottom thereof, the opening being adapted to accommodate rod 27 extending upwardly into coil 16. The lower portion of crucible 36 desirably extends downwardly out of coil 16 whereby the lower portion is out of the electromagnetic

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field established in coil 15 when coil 16 is energized by generator 18.

In a further modification of the source as illustrated in Fig. 4, crucible 37 is positioned completely within coil 15 and is adapted for holding a body of coating metal 38 for batchwise operation, the configuration assumed by the coating metal when molten and under the influence of the electromagnetic field in the coil being shown in Fig. 4.

In a preferred coating process embodying the invention and employing the apparatus shown in Fig. 1, strip material 32 to be coated is mounted on roll 23 and fed across to roll 30. The strip material may be any desired sheet material such as plastic film, textile sheeting, paper or the like.

A rod 27 of coating metal is clamped in collar 26 with an end of the rod extending upwardly into coil 15 at the approximate center of the coil. Rod 27 is of any desired thermally evaporable coating metal such as aluminum, copper, silver, chromium and the like depending upon the material being coated and the coating desired.

Dome 12 is then lowered into sealing engagement with base plate 11 and pumps 13 are put into operation. The chamber is evacuated to a pressure effective to cause the desired evaporation of coating metal when molten. It is usually desirable to carry out the coating process at pressures below about 10 microns Hg. although pressures as high as 100 microns Hg. can be employed. If desired, the apparatus is first employed to degas the material to be coated, degassing being effectively accomplished by repeatedly rolling and unrolling the strip material in the evacuated chamber before the actual coating is begun. If desired, however, degassing can be effected in the chamber by suitable glow discharge means or the material can be degassed in a separate chamber.

Coil 16 is then energized by generator 18, setting up a localized alternating electromagnetic field in the coil, the field having a frequency of 5 to 50 kilocycles per second. The end portion of rod 27 extending into the field is inductively melted with the remainder of the rod outside the field remaining solid. The field, at the relatively low frequencies employed, electromagnetically compacts and laterally supports the molten portion of the rod. The solid portion of the rod provides vertical support for the molten end portion and I have found that no physical supporting means are necessary for lateral support.

The molten end portion under the influence of the electromagnetic field has the appearance of a glowing, wavering finger of molten metal having a rounded tip and it is maintained in the coil without use of a crucible or other container means. Further, the molten tip is self-cleaning since any oxide skin forming on the tip flows down the sides of the end portion to a cooler zone.

Rolls 23 and 30 are thereupon actuated to roll and unroll the strip material to be coated, the strip material being in proximity to the source during passage between the rolls whereupon metal vapors evolved from the rod of coating metal condense on the sheet material. The rate of rotation of the rolls is controlled at the rate necessary to deposit a coating of the desired thickness on the sheet material during passage between the rolls, coating speeds of from 10 to 30 feet per minute or higher being commonly employed.

As the end of the rod of coating metal evaporates away, the rod is progressively advanced upwardly into the electromagnetic field by turning

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feed member 21 which is operable from outside the evacuated chamber. The coating process embodying this invention is operated continuously until the entire roll of sheet material is coated. By supporting the molten metal electromagnetically, it is possible to progressively introduce additional coating metal into the evaporating zone without employing elaborate feed means or interrupting the process by opening the chamber.

When the sheet material is coated to the desired thickness, the coil can be immediately deenergized whereupon the molten tip of the coating rod collapses and flows down the sides of the rod, but more desirably the field strength is gradually decreased until the molten tip begins to solidify.

If desired the process can be carried out employing the modified source shown in Fig. 3. In this embodiment of the invention, a crucible of refractory material such as carbon, graphite, mica, alundum or the like is placed in the coil, preferably with the lower portion of the crucible extending downwardly out of the coil. When a rod of coating metal is employed, as in Fig. 3, the crucible is provided with an opening through the bottom of a diameter just sufficient to accommodate the rod extending upwardly into the coil.

In the process embodying the invention, the molten portion of the rod is supported laterally by the electromagnetic field and is out of lateral contact with the crucible. This greatly minimizes alloying of the coating metal with the crucible which is a common cause of crucible failure. The crucible serves to catch the molten metal when the coil is deenergized and the molten end of the rod collapses, the high viscosity of the molten metal preventing any substantial leakage of metal out of the crucible opening around the rod.

By maintaining the lower portion of the crucible out of the coil, as shown in Fig. 3, the crucible bottom is relatively cool and the molten metal quickly solidifies. Furthermore, the crucible bottom is not weakened by prolonged heating and the tendency of the crucible bottom to break under the impact of the collapsing metal is minimized.

In resuming operation of apparatus employing the source shown in Fig. 3, it is not necessary to remove the fused metal from the preceding run. The rod is merely advanced, pulling the crucible up into the coil. As the metal in the bottom of the crucible melts, the crucible gradually slides down to its original position and the molten portion is compacted away from the crucible walls by the electromagnetic field.

In a further modification of the invention, employing a source as shown in Fig. 4, a refractory crucible having a closed bottom is employed. This form of source is particularly suitable for coating a plurality of individual articles held in the chamber by suitably modified holding means, since a batchwise operation is necessary and a single charge of coating metal in the crucible is sufficient for several single coating operations in many cases.

When such a source is employed, the electromagnetic field laterally compacts and supports the molten metal in a configuration corresponding generally to that shown in Fig. 4. The molten metal is thus out of substantial contact with the crucible walls and crucible life is extended many times the normal crucible life encountered when the molten metal is in direct contact with the crucible walls. As in the previously described embodiment, any oxide skin or other material

gathering on the molten body of metal flows down to the bottom of the crucible leaving a maximum evaporating surface.

In carrying out the process of this invention, field frequencies of from 5 to 50 kilocycles have been found to be most desirable although somewhat lower and somewhat higher frequencies can be employed, generally with less efficacious results. At frequencies of the order of 100-500 kilocycles or higher, such as are commonly employed in high frequency induction heating, the electromagnetic field strength is not effective to laterally compact and support the molten metal out of contact with the crucible.

The invention is applicable for coating a variety of articles under vacuum including lenses, and other optical goods, costume jewelry and the like and is particularly adapted for coating sheet material such as foil, plastic films such as cellulose acetate and the like, textile material of all kinds, paper, leather and the like.

The invention provides simple and effective apparatus for metal coating under vacuum and particularly for continuous coating where a large amount of coating metal is required over a prolonged period of time. By means of the invention, metal coatings of a variety of metals including aluminum, silver, gold and the like are readily obtained and it is notable that copper coatings are entirely feasible by means of this invention whereas copper does not lend itself to many conventional coating processes.

While the invention has been described in considerable detail with reference to certain preferred embodiments thereof, it will be understood that the processes and apparatus embodying the invention may be varied or modified within the spirit and scope of the invention as set forth in the drawings and description and as defined in the appended claims.

What I claim is:

1. Vacuum coating apparatus comprising in combination wall means defining an evacuable chamber, vacuum pumping means communicating with said chamber, source means for establishing in said chamber a localized alternating electromagnetic field effective to vaporize coating metal and having a frequency of 5 to 50 kilocycles per second, said source means comprising an induction heating coil in said chamber with the axis of said coil substantially vertical and an alternating current generator connected to said coil and adapted to supply to said coil alternating current having a frequency of 5 to 50 kilocycles per second, supporting means adapted to engage and support a rod of coating metal of substantial length, said supporting means being below and generally in vertical alignment with said coil and being constructed and arranged to hold said rod with an end portion of said rod extending into said coil, rod feeding means operable from outside said chamber for progressively advancing said rod into said coil as said end portion of said rod evaporates, and holding means in said chamber for disposing material to be coated in proximity to said source means.

2. Vacuum coating apparatus comprising in combination wall means defining an evacuable chamber, vacuum pumping means communicating with said chamber, source means for establishing in said chamber a localized alternating electromagnetic field effective to vaporize coating metal and having a frequency of 5 to 50 kilocycles per second, said source means comprising

an induction heating coil disposed in said chamber with the axis of said coil substantially vertical and current supplying means for energizing said coil at a frequency of 5 to 50 kilocycles per second, supporting means for a rod of coating metal, said supporting means being positioned below and in generally vertical alignment with said coil and being constructed and arranged to hold said rod with an end portion of said rod extending into said coil, crucible means in said chamber in generally vertical alignment with said coil and said supporting means, said crucible having an opening through the bottom thereof sufficient to accommodate said rod with said rod extending from said support means upwardly into said coil through said opening, rod feeding means operable from outside said chamber for progressively advancing said rod into said coil as said end portion of said rod evaporates, and controllable means in said chamber for rolling and unrolling sheet material being coated in coating relation to said source means.

3. Vacuum coating apparatus comprising in combination wall means defining an evacuable chamber, a portion of said wall means being movable into and out of sealing relation with the remainder of said wall means for access into said chamber, vacuum pumping means communicating with said chamber, source means for establishing in said chamber a localized alternating electromagnetic field effective to inductively heat and vaporize coating metal and having a frequency of 5 to 50 kilocycles per second, said source means comprising an induction heating coil disposed in said chamber with the axis of said coil substantially vertical and current supplying means connected with said coil and being adapted to energize said coil with alternating current having a frequency of 5 to 50 kilocycles per second, refractory crucible means disposed in said coil and supported by said coil for holding a body of coating metal to be vaporized in said field, and controllable means for rolling and unrolling sheet material in said chamber in coating relation to said source means, said controllable means comprising paired roller means and means for driving said roller means.

4. Vacuum coating apparatus comprising in combination a gas-tight chamber, means for evacuating said chamber, means for supporting a body of vaporizable coating metal in said chamber in proximity to material to be coated, means in said chamber for holding material in position to be coated, means for inductively melting at least a portion of said body of metal and for electromagnetically compacting and laterally supporting said portion while it is molten, the last-said means including an induction heating coil positioned with the axis of said coil substantially vertical and with said coil disposed around at least said portion of said body of metal and means for supplying to said coil an alternating current having a frequency of 5 to 50 kilocycles per second.

5. Vacuum coating apparatus comprising in combination a gas-tight chamber adapted to be evacuated, means for supporting a rod of metal of substantial length vertically in said chamber, coil means in said chamber, means connected to said coil means for supplying current having a frequency of 5 to 50 kilocycles per second to said coil means, said coil means being disposed with the axis of said coil means substantially vertical and being arranged to surround at least an end portion of said rod, means in said chamber for

holding material in position to be coated, and means for advancing said rod into said coil means as metal evaporates from said end portion surrounded by said coil means.

6. Vacuum coating apparatus comprising in combination wall means defining an evacuable chamber, means for evacuating said chamber, coil means for establishing in said chamber a localized alternating electromagnetic field effective to vaporize coating metal, means connected to said coil means for supplying current having a frequency of 5 to 50 kilocycles per second to said coil means, the axis of said coil means being substantially vertical, support means for holding a rod of coating metal with an end portion of said rod extending substantially vertically into said coil means and being surrounded by said coil means, means in said chamber for holding material in position to be coated, and means operable from outside said chamber for advancing said rod into said coil means as said end portion evaporates.

7. In a coating process in which coating metal is thermally evaporated under vacuum, the steps which comprise inductively melting at least a portion of a body of coating metal, subjecting said molten portion to vacuum effective to cause evaporation of said portion, and substantially throughout said evaporation subjecting said molten portion to an alternating electromagnetic field having a frequency of 5 to 50 kilocycles per second and thereby electromagnetically compacting and laterally supporting said portion of said body of coating metal while said portion is molten, said molten portion being out of lateral contact with physical supporting means, said electromagnetic field being established by coil means disposed about said portion with the axis of said coil means substantially vertical.

8. In a coating process in which coating metal is thermally evaporated under vacuum, the steps which comprise establishing a localized alternating electromagnetic field having a frequency of 5 to 50 kilocycles per second by energizing an induction heating coil disposed with its axis substantially vertical, vertically supporting an elongated body of coating metal with an end portion of said body projecting generally vertically into said coil and being surrounded by said coil, inductively melting said end portion of said elon-

gated body, maintaining said alternating electromagnetic field about said end portion and thereby electromagnetically compacting and laterally supporting said end portion in said field while said end portion is molten, said molten end portion being out of lateral contact with physical supporting means, subjecting said molten end portion to vacuum effective to cause substantial evaporation of said portion, and progressively advancing said elongated body into said coil as said end portion evaporates.

9. The process of continuously coating sheet material which comprises establishing in an evacuated space a localized alternating electromagnetic field having a frequency of 5 to 50 kilocycles per second by energizing an induction heating coil disposed with its axis substantially vertical, vertically supporting an elongated body of coating metal with an end portion of said body extending into said electromagnetic field, said end portion being surrounded by said coil, inductively melting said portion of said body in said field, maintaining said alternating electromagnetic field about said end portion and thereby electromagnetically compacting and supporting said end portion of said body out of lateral contact with physical support means while said end portion is molten, subjecting said molten end portion to vacuum effective to cause substantial evaporation of said portion, passing sheet material to be coated in coating proximity to said field, and progressively advancing said body of coating metal into said coil during said process.

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