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METAL VAPORIZING CRUCIBLE

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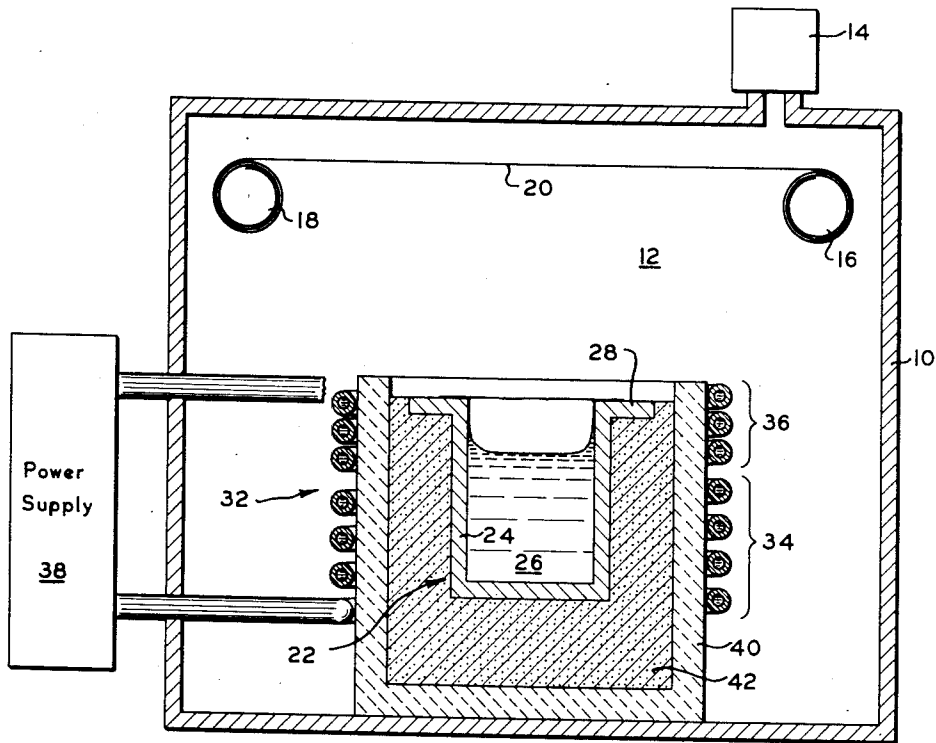


FIG. 1

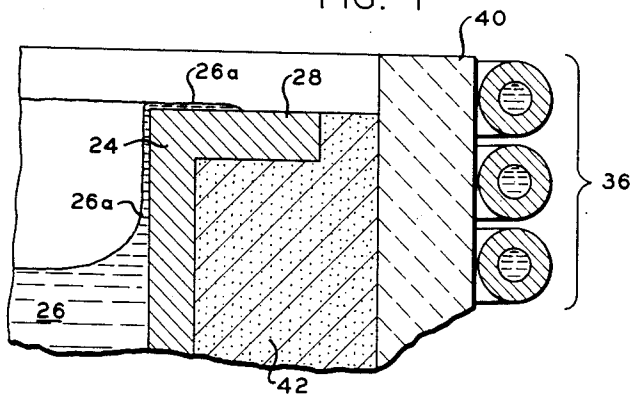


FIG. 2

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METAL VAPORIZING CRUCIBLE

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4 Claims. (Cl. 13-27)

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This invention relates to coating and more particularly to the coating of metals on a base material by melting and evaporating the metal in an attenuated atmosphere.

The coating of metals, such as aluminum, by melting and evaporating the metal in vacuum involves several conditions that should be satisfied. The aluminum must be heated to a temperature on the order of approximately 1200°-1600° C. or higher to give a high rate of vaporization of the aluminum even under very low pressures, such as those in the micron range. At temperatures on the order of 1200° C. or higher, aluminum is extremely reactive and it is necessary to use a crucible for holding the aluminum which is substantially inert to the molten aluminum. It has been found that those crucible materials, such as graphite and carbon, which are relatively inert to the molten aluminum, are also readily wetted by the molten aluminum. In a crucible of this type, it has been found that the molten aluminum has a tendency, due to its ability to wet the material of the crucible, to climb up the side of the crucible and over the edge thereof. This results in a wastage of aluminum and destruction of the furnace since molten aluminum is also highly reactive with most refractory materials which are used to prevent heat loss from the crucible.

Accordingly, it is a principal object of the present invention to provide an apparatus for melting and vaporizing metals, such as aluminum, which permits the use of the most efficient material for forming the metal-holding crucible while overcoming the disadvantage encountered with the climbing of the molten metal out of the crucible.

Another object of the invention is to provide an apparatus of the above type wherein the tendency of the molten metal to climb out of the crucible is utilized to give a higher rate of vaporization of the metal.

Still another object of the invention is to provide an apparatus of the above type which is particularly adapted for use in vaporizing aluminum.

Still another object of the invention is to provide an improved process for vaporizing metals, such as aluminum, which gives higher rates of evaporation than ordinarily achieved.

These and other objects of the invention will in art be obvious and will in part appear hereinafter.

The invention accordingly comprises the ap-

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paratus possessing the construction, combination of elements and arrangement of parts, and the process involving the several steps and the relation and the order of one or more of such steps with respect to each of the others which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings wherein:

Fig. 1 is an exaggerated, diagrammatic, partially sectional view of one preferred form of the invention; and

Fig. 2 is an exaggerated, enlarged, sectional view of a portion of Fig. 1.

In the present invention the apparatus for evaporating and depositing the metal coating in vacuum preferably includes a vacuum-tight chamber, means for evacuating the chamber, means for supporting the base material in the chamber, and means for melting and vaporizing the metal. This vaporizing means, in a preferred form, comprises a means forming a crucible which is to hold the metal to be melted and vaporized. The vaporizing means also includes a means for heating the crucible, and thus the metal therein, to a temperature sufficient to give high rates of evaporation at very low pressures (i. e., in the micron range). The heating means, in a preferred form, comprises an induction heating means, such as an induction coil, which is capable of inducing eddy currents in the metal and in the walls of the crucible to heat the metal up to the desired high temperature (i. e., about 1300°-1350° C.).

Since the crucible, as mentioned previously, preferably comprises a material which is wettable by the molten metal, the molten metal has a decided tendency to climb up the walls of the crucible and tends to flow over the upper edges thereof.

In the present invention this disadvantage is overcome, and the tendency of the metal to climb out of the crucible is utilized to increase the evaporation rate of the metal as well as to prevent damage to the elements surrounding the crucible. These advantages are achieved by maintaining a sufficient temperature differential between the upper edge of the crucible and the main body portion thereof so that this upper edge is at a temperature in the neighborhood of about 100° C. higher than the temperature of

the molten metal in the crucible. This hot upper edge thus furnishes an additional vaporizing area, and increases substantially the total amount of metal vaporized. The upper edge of the crucible is preferably in the form of a lip at the top of the main body portion of the crucible, and the heating means is so arranged that the lip is heated to the desired higher temperature. This is preferably accomplished, with the induction heating system, by providing a tighter electromagnetic coupling between the lip and the induction coil than between the body portion and the induction coil. This tighter coupling is achieved by providing more turns adjacent to the lip, by having the coil nearer the lip than the body, or by using both such arrangements.

The vaporizing means also preferably includes a means for minimizing radiation heat transfer from the crucible, thereby resulting in a saving of power. This loss of heat is preferably prevented by providing a second crucible, made of a nonconductor of electricity, surrounding the metal-holding crucible and a refractory packing between the two crucibles. The induction coil is preferably positioned outside of, and concentric with, both crucibles.

Referring now to Fig. 1, the apparatus of the present invention is shown as comprising a vacuum-tight housing 10 providing a vacuum chamber 12, this chamber being kept at a pressure in the micron range by means of a vacuum pump system schematically indicated at 14. Within the chamber 12 there is provided a means for supporting a base material to be coated, this means being shown schematically as a first spool 16 and a second spool 18 carrying therebetween the base material 20.

The means for vaporizing the metal comprises a metal-holding crucible 22 having a main body portion 24, in which the metal 26 is to be held in molten condition and heated to a temperature sufficient to vaporize the metal at a high rate under the pressure existing in the vacuum chamber 12. Extending from the top of the main body portion 24, there is provided a lip 28 which is preferably formed integrally with the body portion 24. For providing heat to the metal 26 and the metal-holding crucible 22, there is included a heating means, schematically indicated at 32. This heating means preferably comprises an induction coil having a portion 34 for heating the main body of the crucible and the metal carried thereby and a portion 36 for heating the lip 28 of the metal-holding crucible. A suitable power supply 38 is provided for furnishing a high frequency current to the induction coil 34, 36. The induction coil 34, 36 is preferably a water-cooled coil, such as a copper tubing, through the interior of which water is adapted to be circulated. As can be seen from Fig. 1, the turns in portion 36 of the coil, adjacent the lip 28, are closer together than are the turns in portion 34 of the coil, adjacent the main body portion of the crucible.

For preventing radiation heat loss from the crucible 22, there is provided an outer crucible 40, preferably made of a refractory material which does not conduct electricity, and a refractory packing 42 between the metal-holding crucible 22 and the outer refractory crucible 40. Means for feeding metal to the crucible are also preferably provided but not illustrated. Such means may comprise a wire-feeding mechanism

which feeds wire to the crucible at a rate equal to the rate of evaporation of the aluminum.

In a preferred form of the invention, the metal-holding crucible 22 is preferably formed of a current-conducting material, such as graphite or a graphite-carbon mixture of the type commercially available under the trade-name "Graphitar." The graphite-carbon mixture preferably has an apparent density of about 1.65 and the crucible preferably includes a zirconium carbide inner skin. This skin is formed by adding zirconia to the melt or by applying a zirconia slurry to the inner surface of the crucible prior to melting the aluminum. This zirconium carbide skin is particularly effective in preventing the formation of aluminum carbide during the evaporation of the aluminum. The outer crucible 40 preferably comprises a refractory material, such as silica, while the refractory packing 42 preferably comprises zirconia or beryllia. The induction coil is preferably provided with a suitable source of high frequency current of approximately 100,000 to 500,000 cycles per second from a usual high frequency power source. When a "Graphitar" crucible 22 is employed for vaporizing aluminum, the resistivity of the charge (including the crucible) is about 1000. With such a charge and a frequency of about 100,000 cycles, the skin depth of the induced current is approximately 0.2 inch at the temperature employed. The wall of the crucible is thus preferably made slightly thinner than 0.2 inch so that some of the induced current flows in the molten aluminum charge.

The use of the invention, illustrated in Figs. 1 and 2, will now be described with particular reference to the vaporization of aluminum. A quantity of aluminum 26 is provided in the crucible 22 in the form of powder, rod, pellets, or the like. Chamber 12 is evacuated by the pump 14 to about 0.2 micron pressure and power is supplied to the induction coil 34, 36. The amount of aluminum supplied to the crucible 22 is preferably high enough to fill the crucible to within a quarter of an inch or a half an inch from the top thereof. As can be seen from an examination of Fig. 2, the molten aluminum tends to creep up the walls of the crucible and over the top surface of the lip 28 thereof. This creeping meniscus of molten aluminum is indicated at 26a, the thickness thereof being grossly exaggerated for illustrative purposes.

While the aluminum is being melted in the body portion 24 of crucible 22, the lip 28 is also being heated by eddy currents induced therein from the top coil portion 36. As mentioned previously, there is a closer electromagnetic coupling between the coil portion 36 and lip 28 than there is between coil portion 34 and the crucible body 24. This is due both to the fact that the lip 28 extends outwardly towards the coil 36, and to the fact that the spacing between the turns in coil portion 36 is less than the spacing between the turns in coil portion 34. By means of this arrangement, lip 28 has a greater heat input thereto and will remain at a substantially higher temperature than the temperature of the molten aluminum 26 in the body portion 24 of the crucible. Lip 28, due to the high heat input thereto, will be maintained at this higher temperature despite the fact that it has a relatively large heat-radiating upper surface. Since the lip 28 is at this higher temperature, the molten aluminum, which creeps into contact with the hot lip 28, is evaporated more

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rapidly than the aluminum which is being evaporated from the main body of molten aluminum. This evaporation of the aluminum in contact with the lip 28 is maintained sufficiently high so that none of the aluminum is allowed to creep beyond the outer edge of the lip 28, the molten aluminum starting across the top of lip 28 being completely evaporated before it can reach the outer edge.

It can thus be seen that the present invention, in addition to preventing overflow of the molten aluminum from the metal-holding crucible, also increases the amount of aluminum being vaporized by providing a greater surface area for evaporating this aluminum. The lip 28 thus acts as a wick for increasing the evaporation rate. With a device of the type schematically shown in Figs. 1 and 2, it is possible to obtain evaporation rates above 4 grams per minute per square inch of surface area at the top of the molten aluminum within the body portion 24. This high evaporation rate is readily achieved when operating at chamber pressures of about 0.2 micron and at aluminum temperatures on the order of 1350° C.

Since certain changes may be made in the above apparatus and process without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, or shown in the accompanying drawings, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. For use in an apparatus for the vapor deposition coating of a flexible substrate by moving the substrate past a source of metal vapors positioned in an evacuated coating chamber, a crucible for holding molten metal to be evaporated, said crucible comprising a material substantially inert to such molten metal and wettable by said molten metal, said crucible having a main body portion for holding said molten metal, lip means extending from said main body portion adjacent the upper edge thereof, and means for heating said crucible to thereby raise the temperature of said molten metal in said crucible to above 1200° C., said heating means comprising a first heating portion for heating said crucible

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body and a second heating portion for heating said lip means, said second heating portion being arranged to apply a sufficient heat input to said lip means to maintain said lip means at a substantially higher temperature than the temperature of the molten metal in the crucible so that said lip means serves to vaporize all molten metal reaching said lip.

2. The apparatus of claim 1 wherein said apparatus includes means for minimizing radiation heat losses from said crucible body portion, said last-named means comprising a second crucible surrounding said metal-holding crucible and a refractory packing between said crucibles.

3. The apparatus of claim 1 wherein said heating means comprises an induction coil, said coil having a larger number of turns per unit length adjacent said lip means than adjacent said body portion, the turns of said coil adjacent said lip means comprising said second heating portion and the turns of said coil adjacent said body portion comprising said first heating portion.

4. The apparatus of claim 3 wherein said lip means extends outwardly from said body portion, said induction coil being closer to said lip means than to said body portion.

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