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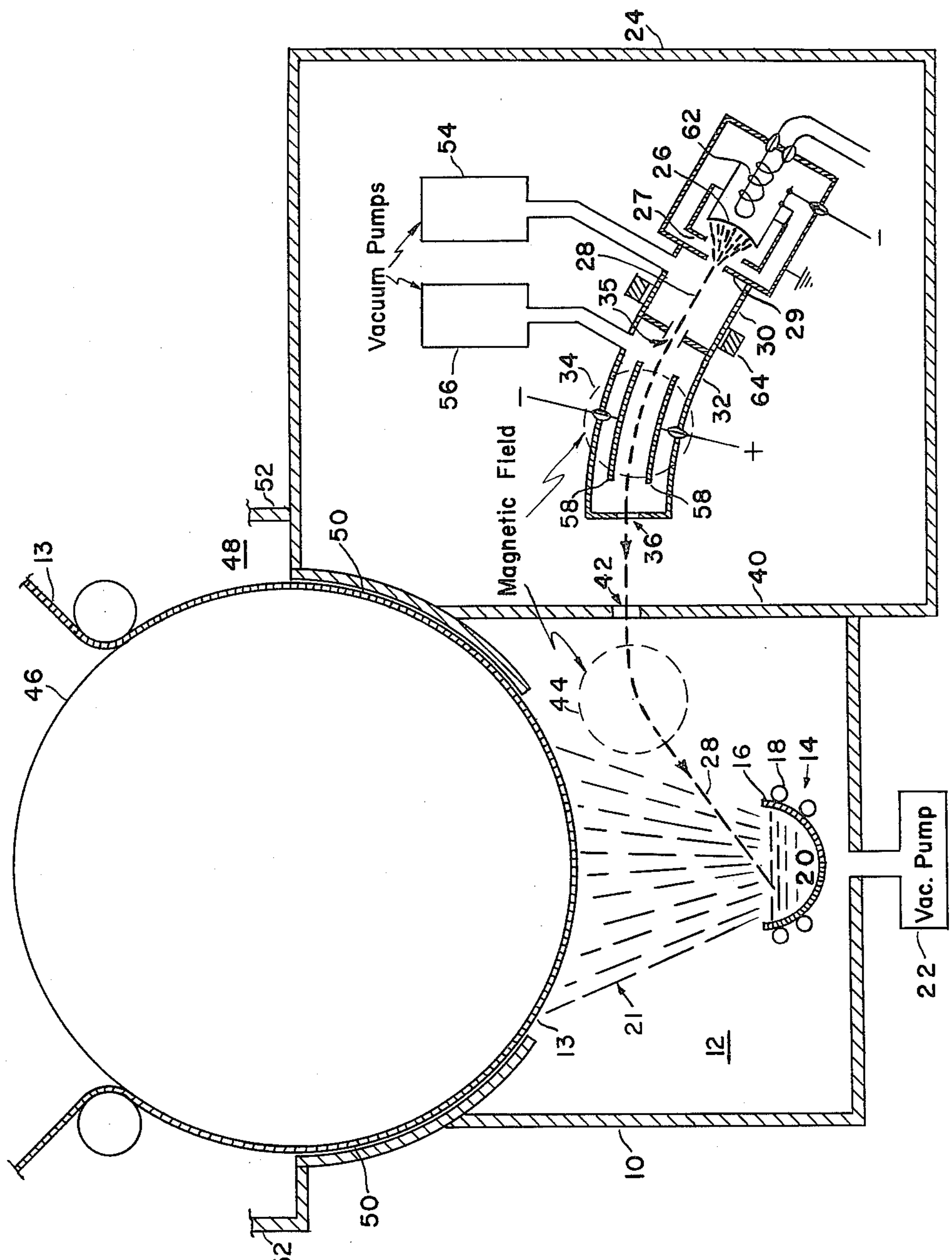

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IMPROVEMENT IN VACUUM COATING APPARATUS COMPRISING AN ION TRAP FOR THE ELECTRON GUN THEREOF

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This invention relates to coating and more particularly to vapor deposition coating under high vacuum wherein a material such as aluminum is vaporized, and the vapors are deposited on a substrate such as paper and the like which is moved through the stream of aluminum vapors. While the invention is of considerable utility with respect to many metals and non-metals, for convenience of illustration it will be primarily described in connection with the vaporization of aluminum under high vacuum conditions to provide a vapor deposited aluminum coating on a substrate.

The vacuum vapor deposition of aluminum has recently assumed considerable commercial importance in the metalizing of plastics, such as polyethylene terephthalate, paper, textiles and metals, such as black iron. One of the principal problems in the operation of coating devices of this type has been the provision of a source of aluminum vapors which will run for many hours at an elevated temperature on the order of 1100° C. to 1300° C. so as to provide a high concentration of aluminum vapors to permit rapid coating of a substrate moved through the aluminum vapors. When wide strips of paper, for example 60 inches wide, are to be coated at speeds from 1000 to 2000 feet per minute, a high-temperature, large source for aluminum vapors is required. It is also highly desirable that the source be capable of operating for many hours without replacement or repair. Considerable advance has been made recently in solving these many problems. It has long been a primary objective in the art to provide a source of high temperature aluminum vapors which will have an almost indefinite life of operation.

Accordingly, it is a principal object of the present invention to provide a source of aluminum vapors in a vacuum coating device which is capable of operating at elevated molten aluminum temperatures for long periods of time.

Another object of the invention is to provide a source of aluminum vapors which is cheap, efficient and reliable.

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

The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts 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 drawing, which is a diagrammatic, schematic, sectional view of a preferred embodiment of the invention.

In the present invention, a stream of high energy electrons is utilized as a source of energy for heating the aluminum to be vaporized in the vacuum coating chamber. It is recognized that the use of electron bombardment as a source of heat for vaporizing aluminum and other materials is not basically new. The suggestion has been before the art for many years. For example see the patents to Ruhle No. 2,423,729, Brown No. 2,621,625 and Steigerwald No. 2,746,420. However, so far as is known, none of the arrangements described in these patents has ever achieved any substantial degree of commercial success. The reason for this is believed to reside in the fact that electron beam melting and vaporizing has involved high voltages and high energy electrons. In the Ruhle and Steigerwald arrangements, the electron beams are directed at the surface of the aluminum to be vaporized and the aluminum vapors, in turn, travel in all directions, including directly towards the source of electrons. This can result in spark discharges and destruction of the electron source by erosion of the hot filament due to positive ion bombardment. This occurs despite the advantage offered by the Ruhle and Steigerwald systems that the kinetic energy of the electron beam is converted to thermal energy (heat) in the aluminum right at the surface thereof, which is where it is ultimately needed to accomplish its vaporizing function. In the Brown apparatus the aluminum is supported in a cup which is heated by electron bombardment. While this works satisfactorily for a while, it is difficult to maintain high temperature molten aluminum in contact with any solid body for an indefinite period of time.

In the present invention, the electron beam used for heating the molten aluminum is directed at the surface of the aluminum to be vaporized so that the heat generated is localized at the vaporizing surface. Accordingly, the molten aluminum may be confined in a cooled crucible, for example, so that the aluminum in contact with the wall of the crucible is either solid or at such a low temperature that reaction with the crucible material is negligible. In fact, the aluminum can form its own crucible by proper cooling of a mass of aluminum, for example.

The difficulties of the prior art devices utilizing electron beam vaporization are avoided by positioning the cathode for emitting the electrons in a portion of the coating apparatus which is well shielded from vapors emitted from the hot aluminum. The electrons emitted from the cathode are focused into a beam, which beam is projected into an initial path. The projection of this initial path misses the surface to be heated so that aluminum atoms traveling in a straight line from the heated aluminum surface cannot travel parallel to the focused initial path of the electrons. The electron beam, after passing the vapor shield is bent towards the surface to be heated so that the beam impinges on this surface.

In a preferred embodiment of the invention, the electron beam passes through a magnetic field to accomplish the bending thereof to a substantial degree. The apparatus also preferably includes an ion trap for trapping both positive and negative ions tending to migrate from the coating chamber towards the electron-emitting filament. One preferred embodiment of this ion trap constitutes a means for generating an electrostatic potential transversely of the path of the electron beam, this potential being ineffective to cause substantial deviation of the high energy electrons in the beam, but being capable of causing substantial deflection of low energy ions traveling in a direction opposite to the electrons in the beam.

Referring now to the drawing, there is shown a schematic, diagrammatic representation of one preferred embodiment of the invention, wherein **10** represents a wall defining a chamber **12** in which aluminum is evaporated from a suitable source **14** so as to be deposited on a substrate **13** which is moved through the stream of aluminum vapors. The source **14** comprises a crucible **16** which is shown as being cooled by a cooling coil **18**. This crucible **16** supports therein a pool **20** of molten aluminum in position to supply a stream of aluminum vapors **21** extending upwardly to condense on the moving substrate **13**. The aluminum **20** in the crucible **16** is heated by a beam of electrons schematically indicated at **28**. This electron beam comes from an auxiliary chamber **24** containing an electron gun which is schematically indicated as including a hemispherical, high-temperature cathode 26, a focusing electrode 27 and an accelerating anode 29. Several pumped chambers 30 and 32 are provided through which the electron beam is projected in its travel from the cathode to the surface of the molten aluminum 20. As the electron beam passes through the chamber 32, it is bent slightly by means of a transverse magnetic field schematically indicated at 34 so that the beam 28 is projected through the electron gun assembly, through holes 35 and 36 and also through an aligned hole 42 in the wall 40 serving as a vapor shield to prevent aluminum vapors from contacing the electron gun. After the electron beam 28 has passed through hole 42, it passes through another magnetic field schematically indicated at 44 so that it is bent downwardly to impinge on the surface of molten aluminum 20. The electron beam heats this molten aluminum surface to a very high temperature (on the order of 1200 to 1300° C.) so as to vaporize the aluminum at the high vacuum, which is maintained in the coating chamber 12. The substrate to be coated is illustrated as a flexible sheet such as paper which is supported by a large drum 46 as it is moved through a pair of openings 50 defining high impedance paths which prevent substantial flow of air from intermediate vacuum chamber 48 to high vacuum coating chamber 12. Only portions of the casing 52 defining the intermediate vacuum chamber 48 are illustrated.

Vacuum pumps 54 and 56 are schematically indicated for maintaining the various chambers in the electron gun at a very high vacuum so as to prevent damage to the high temperature cathode 26. A separate pump (not shown) may be provided for evacuating chamber 24 to a requisite low pressure.

As illustrated, the electron gun assembly also preferably is provided with a pair of capacitor plates 58 positioned on opposite sides of the path of travel of the electron beam 28. The purpose of these capacitor plates is to act as ion traps for deflecting relatively slow-moving ions which might otherwise tend to travel countercurrent to the flow of electrons. The positive ions will be attracted to the negative plate and the negative ions will be attracted to the positive plate. Since the electrons will be moving at extremely high velocities, they will be only slightly affected by the electrostatic field between the plates 58. However, the electron beam will be strongly deflected by the transverse magnetic field. The slow-moving positive and negative ions will only be slightly affected by the magnetic field, but strongly attracted or repelled, as the case may be, by the electrostatic field.

In the operation of the device schematically illustrated, the substrate such as paper, plastic or the like is threaded through the plate seals 50 into the coating chamber. The substrate can be introduced from the outside through appropriate seals (not illustrated) or it can be mounted in the intermediate vacuum chamber 48. The intermediate vacuum chamber is pumped down to a pressure on the order of 50 to 100 microns and the high vacuum coating chamber is preferably pumped down by pump 22 to a pressure of less than 1 micron Hg Abs. Pumps 54 and 56 will pump the interior of the electron gun to very low pressures, such as one-hundredth of a micron adjacent the cathode 26. The cathode is heated indirectly by means of the filament 62. The cathode is held at a highly negative potential on the order of 20,000 volts with respect to the accelerating anode 29. The electrons emitted from the cathode are focused by focusing electrode 27 into a beam 28. The electrons are accelerated by means of the anode 29 to extremely high velocities and can be further focused by an appropriate focusing coil 64. As the beam of electrons passes through the magnetic field 34, it is bent slightly so as to pass through the aligned openings 36 and 42 and then deflected again by magnetic field 44 so that the beam impinges on the surface of aluminum 20.

The beam of electrons may be of very high power, as much as 60,000 watts. This power, representing the kinetic energy of the electrons, is converted to heat when the beam strikes the surface of aluminum 20. The surface of the aluminum is raised to a very high temperature on the order of 1200 to 1300° C. so that copious quantities of aluminum vapors are released to the vacuum coating chamber 12. Due to the high vacuum in the coating chamber 12 the aluminum vapors travel in substantially straight lines from the surface of the aluminum pool 20. Most of these vapors condense on the substrate 13 which is moved over the surface of the aluminum source while other vapors condense on the interior walls of the coating chamber 12. The water cooling coil 13 maintains the crucible 16 at a relatively low temperature, for example 700 to 800° C., at which point the aluminum is very unreactive with many metals and refractories such as carbon. Aluminum can be fed to replenish the pool 20 continuously or intermittently by suitable wire or powder feeding equipment of known types. Equally, molten aluminum can be continuously or intermittently added to the pool.

The present invention, as described above, provides a long-life source of copious quantities of aluminum vapors for coating a fast-moving substrate. This is made possible by a number of considerations. In the first place, the source of electrons used for heating the aluminum to vaporization temperature is far removed from the locus of the aluminum vapors. Accordingly, there is no accelerating electrical field in the presence of any appreciable density of metallic vapors. Thus a high metallic vapor density can be achieved in the coating chamber without danger of disastrous arcing in the electrical system.

In the second place, the present invention provides a combination of geometrical and electrical shields which can prevent plugging of the electron source by condensed aluminum vapors or destruction of the high temperature electron source by ion bombardment thereof. Neutral atoms and molecules are prevented from entering the inner chamber 30 of the electron gun by means of the mechanical barriers associated with the openings 42, 36 and 35. Since the high energy aluminum vapors emitted from the source 20 will travel in straight lines they cannot pass through all three of the openings 42, 36 and 35. Accordingly, the great majority of neutral aluminum atoms and molecules 21 are of no problem whatsoever. However, a few atoms 21 may (due to thermal energy and collision with other atoms) travel in such a direction that they can pass through aligned holes 42 and 36. If these atoms pass through these two aligned holes without being ionized, they will strike one of the capacitor plates 58 or the inner surface of the tube 32. If they are ionized due to the high-energy electron beam also passing through these holes, they will be attracted toward one of these capacitor plates 58 due to the electrostatic field between the plates. Accordingly, essentially no neutral atoms or molecules will pass through the hole 35 into the chamber 30 in position to be ionized and bombard the hot cathode 26. If it is found that, under any particular set of circumstances, too many neutral molecules or atoms are migrating into the chamber 30, additional electrical capacitor plates and mechanical shields can be provided in chamber 30 with suitable magnetic bending of the high energy electron beam around such mechanical shields. However, for most purposes, such additional electrical and mechanical shielding of the cathode should not be necessary.

While the deflecting magnetic field 44 has been illustrated as a constant magnetic field, it can be made with varying intensity so as to provide a "scanning" of the electron beam across the surface of the molten aluminum to assure uniform heating thereof.

While a preferred embodiment has been described above, numerous modifications thereof may be practiced without departing from the spirit of the invention. For example, the substrate can be paper, plastic, textile, metal or only the bare drum. In this latter case, the drum is first coated with a release agent, then with a layer of molten aluminum and thereafter the thin layer of aluminum is transferred, by means of an adhesive bond, to another substrate, such as paper, textiles or the like. This technique is disclosed in the copending application of Stauffer, Serial No. 721,888, filed March 17, 1958.

Since certain changes may be made in the above apparatus 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 be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In apparatus for heating a metal to a temperature sufficiently high to vaporize said metal in an evacuated chamber by directing a beam of electrons against a surface of a mass of said metal to be heated to said high temperature, the improvement which comprises a cathode for emitting electrons, a means including an accelerating anode for accelerating said electrons to a high energy level and for focusing the electrons emitted from the cathode into a beam and projecting the beam of electrons in a given path, said path missing the surface to be heated, a vapor shield between the focusing means and the surface to be heated, magnetic means positioned to bend the electron beam so that the electron beam is directed towards the surface to be heated when said beam is beyond the point of interception of the beam by the shield, and means positioned between said shield and said anode for creating an electrostatic field transverse to the electron beam, said transverse electrostatic field trapping ions migrating towards said cathode.

2. In apparatus for coating a substrate wherein the substrate is moved above a source of coating vapors in an evacuated coating chamber and wherein a beam of electrons is directed against a surface of a mass of material to be vaporized so as to heat a portion of the surface to its vaporization temperature, the improvement which comprises a cathode for emitting electrons, a means including an accelerating anode for accelerating said electrons to a high energy level and for focusing the electrons emitted from the cathode into a beam and projecting the beam of electrons in a given path, said path missing the surface to be heated, means for protecting the cathode and beam forming means from direct impingement of coating vapors thereon, means for creating an electrostatic field transverse to the electron beam, said transverse electrostatic field being located between said anode and said protecting means, said transverse electrostatic field trapping positive ions migrating towards said cathode, and magnetic means positioned to bend the electron beam through a substantial angle so that the electron beam is finally directed towards the surface to be heated.

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