219-121 SR FERENCE
MTR04 XR 3,526,206

United States Patent

[11] 3,526,206

[72] Inventor **Charles H. Jones**
Murrysville, Pennsylvania

[21] Appl. No. **749,086**
[22] Filed **July 31, 1968**
[45] Patented **Sept. 1, 1970**

[73] Assignee **Westinghouse Electric Corporation**
Pittsburgh, Pennsylvania
a corporation of Pennsylvania

[54] COATING APPARATUS INCLUDING ELECTRON BEAM EVAPORATING MEANS

6 Claims, 16 Drawing Figs.

[52] **U.S. Cl.** **118/49.1,** 313/338, 219/121
[51] **Int. Cl.** **C23c 13/08**
[50] **Field of Search** 118/49.1, 49.5; 313/338, 302; 219/121EB; 13/31, 13; 117/93, 93.3, 106–107.1; 250/41.9

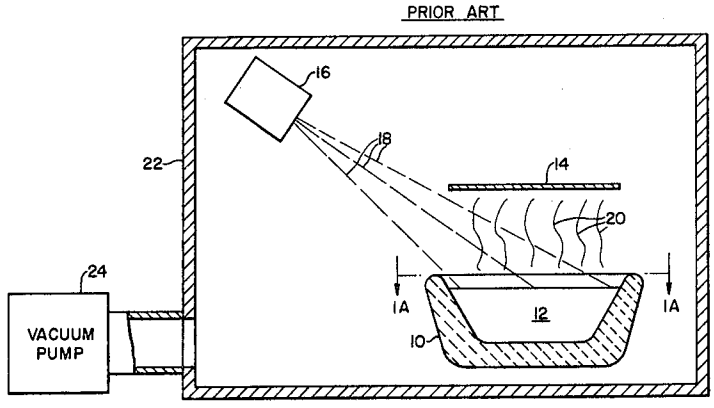
[56] **References Cited**

UNITED STATES PATENTS

1,418,022	5/1922	Reisz	313/302X
1,496,311	6/1924	Hammond, Jr.	313/302X
1,765,413	6/1930	Fruth	313/302X
2,173,498	9/1939	Schlesinger	313/338X
2,581,243	1/1952	Dodds	313/338
2,817,040	12/1957	Hull	313/338X
3,118,050	1/1964	Hetherington	219/121(EB)UX
3,132,198	5/1964	Du Bois et al.	219/121(EB)UX
3,183,563	5/1965	Smith, Jr.	118/49.1X
3,235,647	2/1966	Hanks	219/121(EB)UX
3,244,855	4/1966	Cauley	219/121(EB)UX
3,270,233	8/1966	Dietrich	219/121(EB)UX
3,271,179	9/1966	Smith, Jr.	118/49.1X
3,343,828	9/1967	Hunt	219/121(EB)UX
3,364,296	1/1968	Smith, Jr.	13/31
3,389,210	6/1968	Whitson et al.	13/31
3,420,977	1/1969	Hanks et al.	219/121(EB)UX
3,432,335	3/1969	Schiller	118/49.1X
3,437,734	4/1969	Roman et al.	118/49.5
3,450,824	6/1969	Hanks et al.	13/31

Primary Examiner—Morris Kaplan
Attorney—F. Shapoe and L. P. Johns

ABSTRACT: A system for applying a coating material on a substrate by vapor deposition wherein the surface of a body of a coating material is bombarded by a beam of electrons from an electron beam source comprising one or more electron guns. The parameters of each gun, its location at about 270° to the coating surface, and a magnetic field are specifically established to provide a beam having a cross-sectional impingement area that achieves a substantially uniform beam pattern and current distribution at the surface of the molten coating material to provide a high coating efficiency. The gun cathode is generally concave and formed of spaced apart sheet-like segments. Each segment is combined with a separate heater means whereby to produce a composite beam of varying intensity.



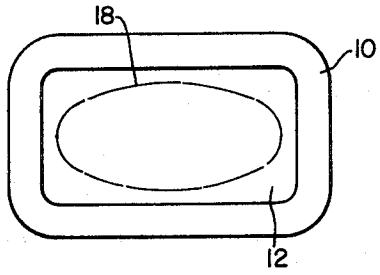
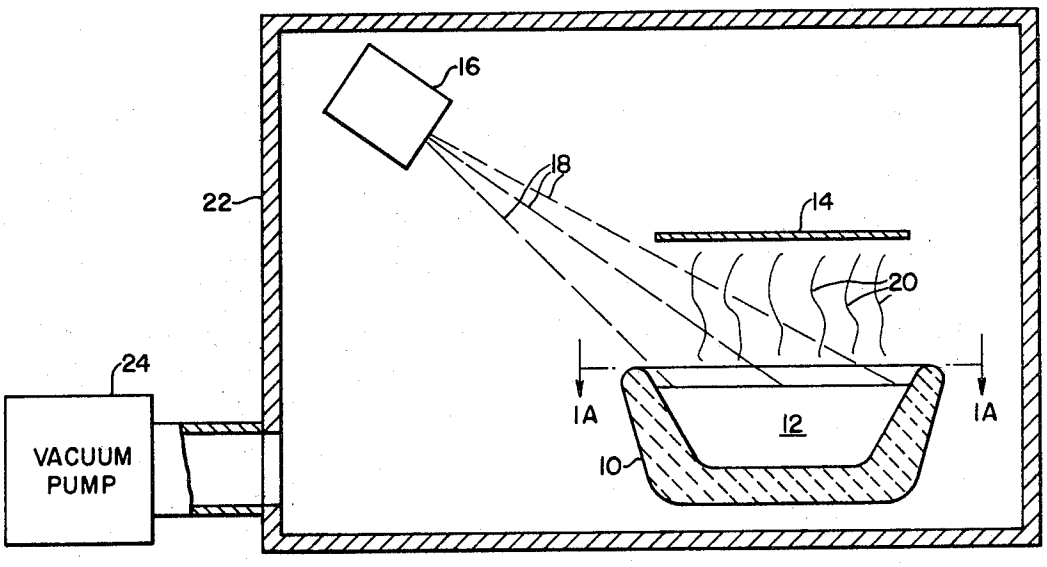


FIG. IA.

FIG. I.
PRIOR ART



WITNESSES

Theodore F. Wrobel

James F. Young

INVENTOR

Charles H. Jones

BY Lee P. Johns

ATTORNEY

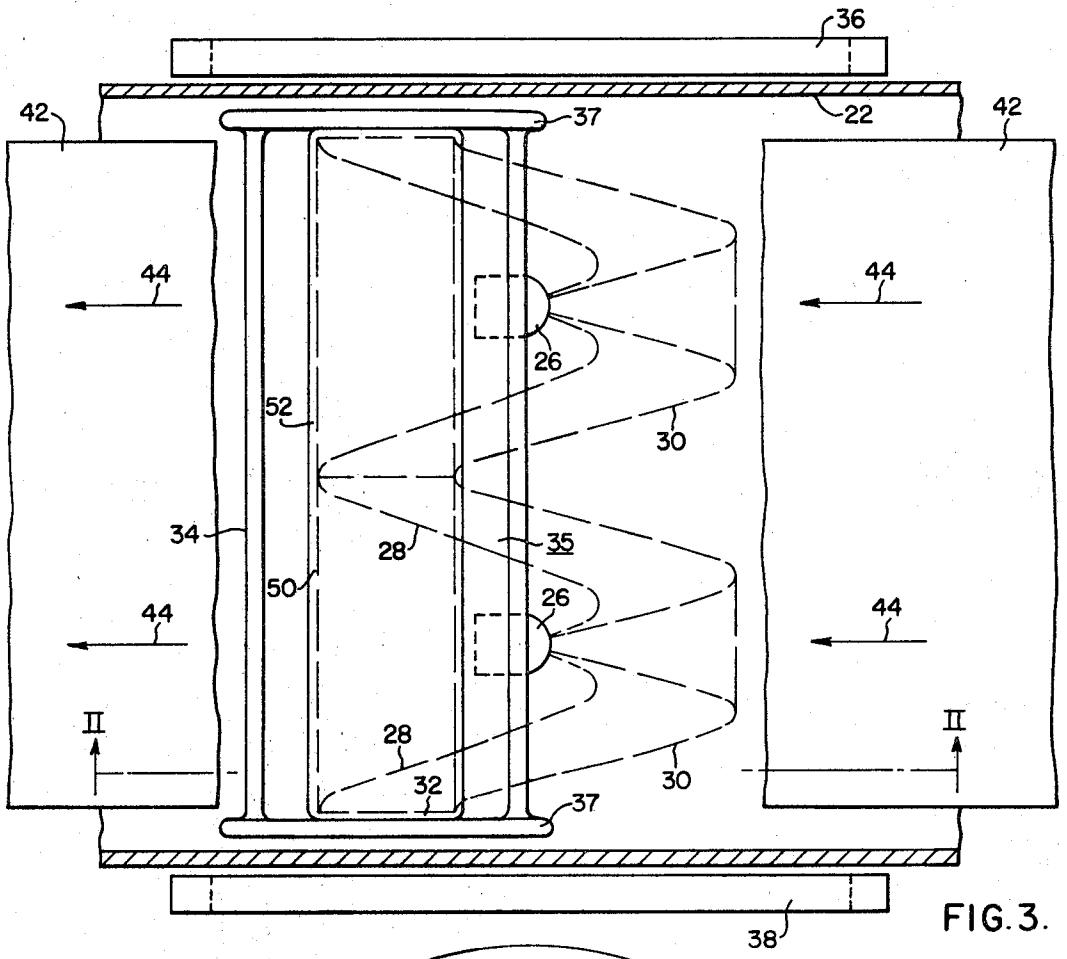

36
42
37
22
42
44
44
26
52
30
34
28
35
50
26
44
44
II
28
II
32
30
37
38

FIG. 3.

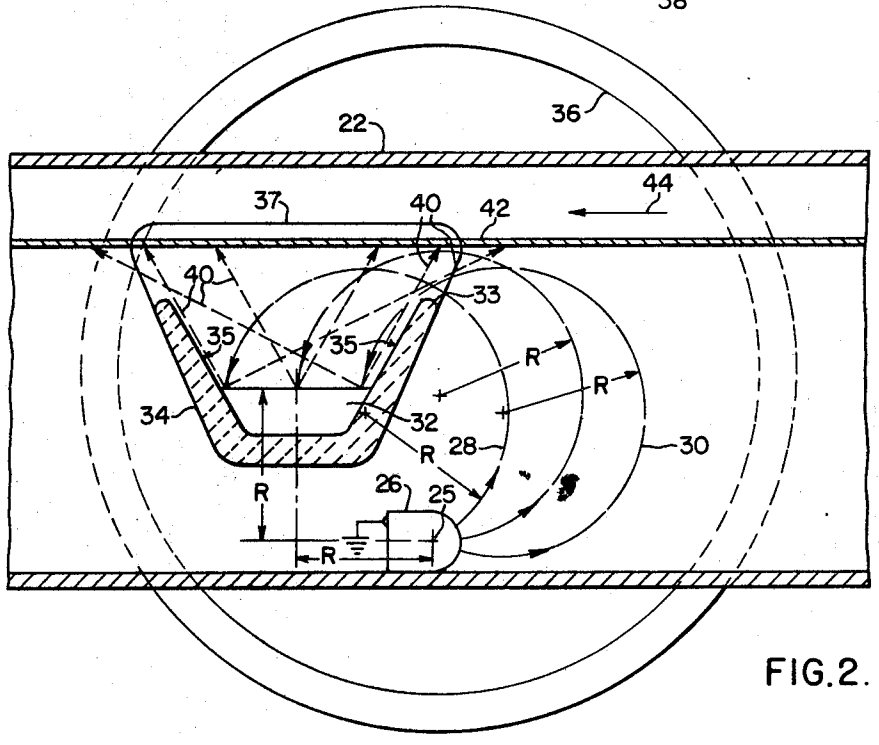
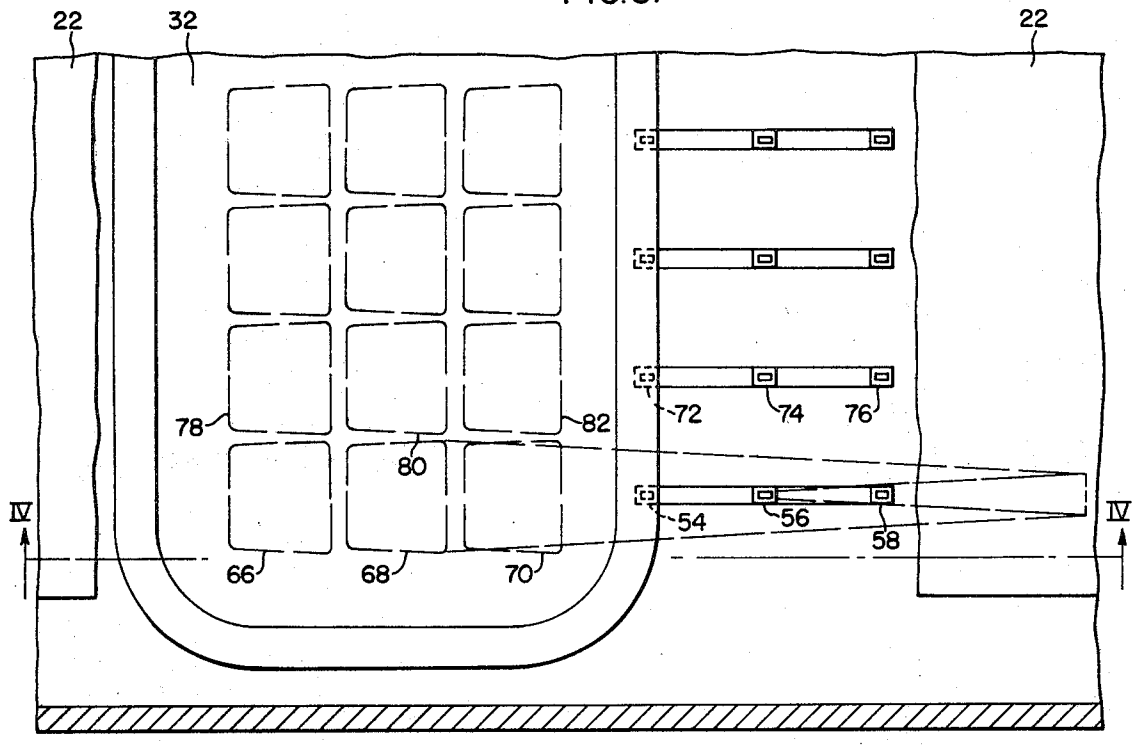

22
36
37
40
42
44
40
33
35
35
R
R
34
32
R
28
30
26
25
R
R

FIG. 2.

FIG.5.


22
32
22
78
82
80
72
74
76
IV
IV
54
56
58
66
68
70

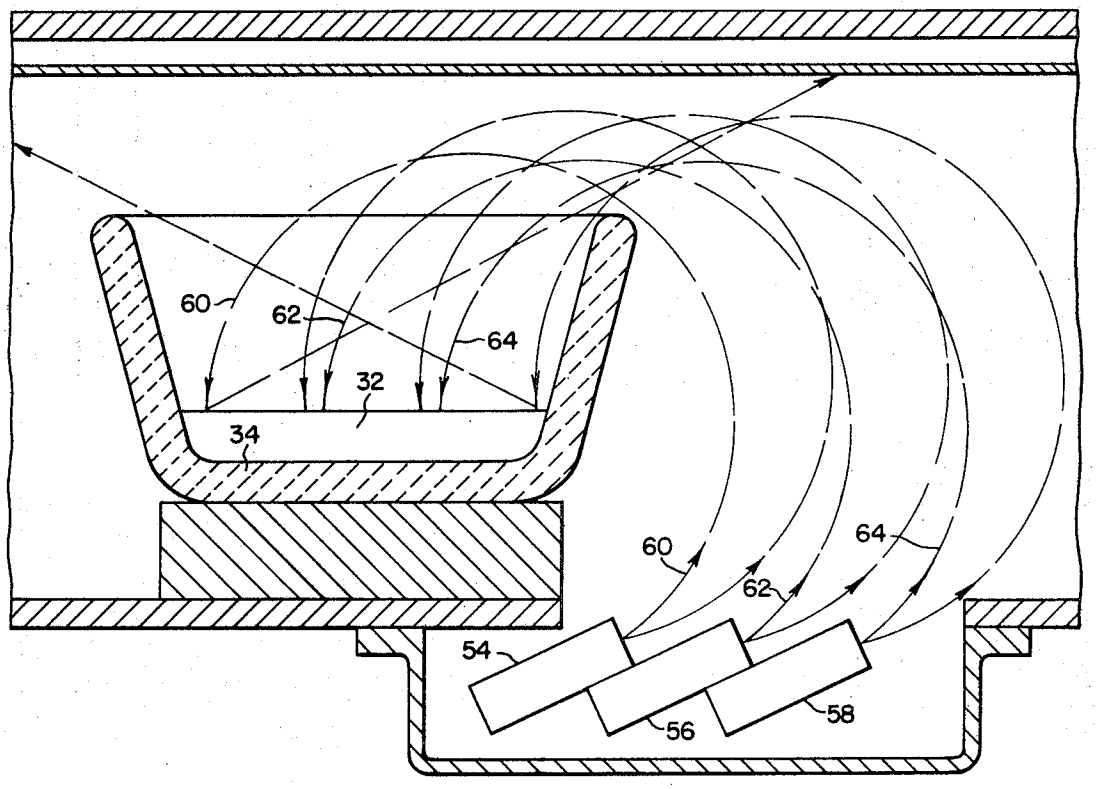
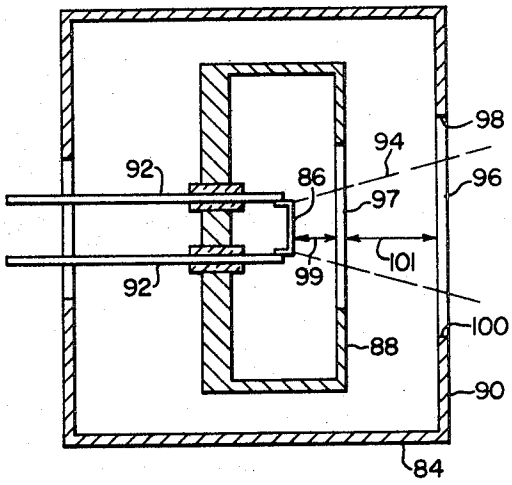

60
62
64
32
34
60
62
64
54
56
58

FIG.4.

FIG. 6.



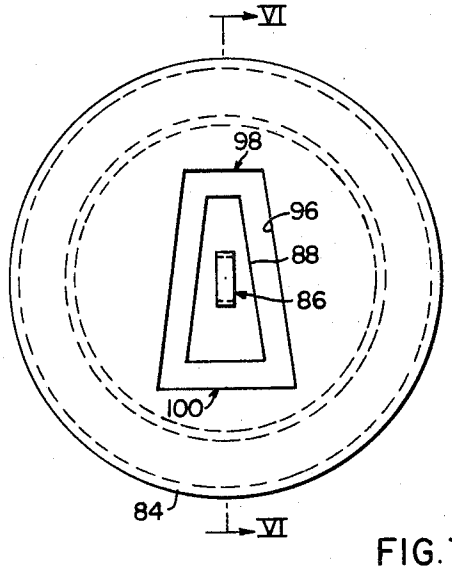


FIG. 7.

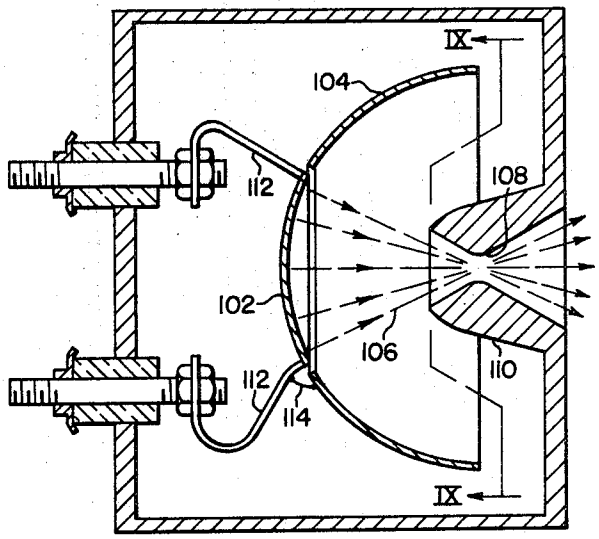


FIG. 8.

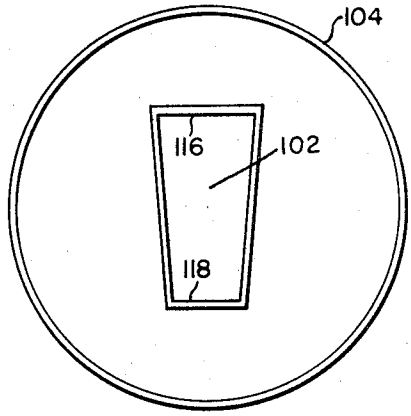


FIG. 9.

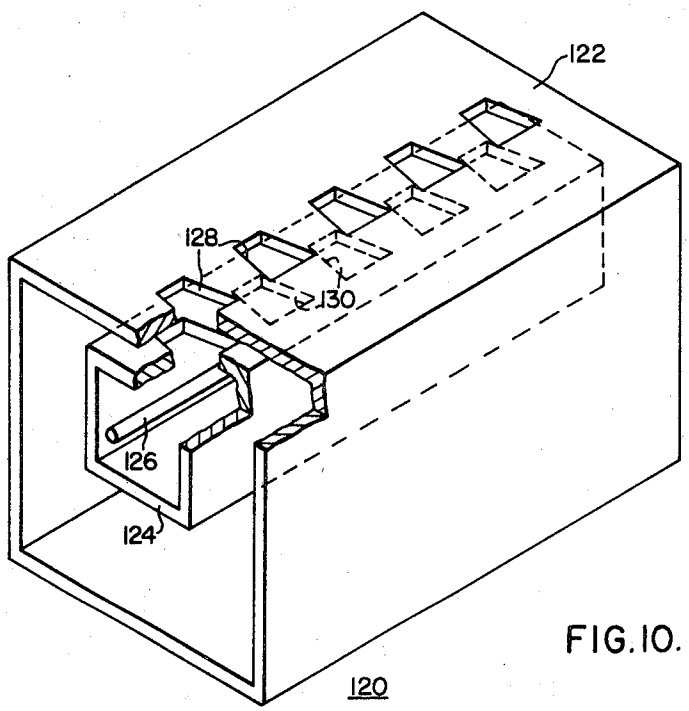


FIG. 10.

FIG. 11.

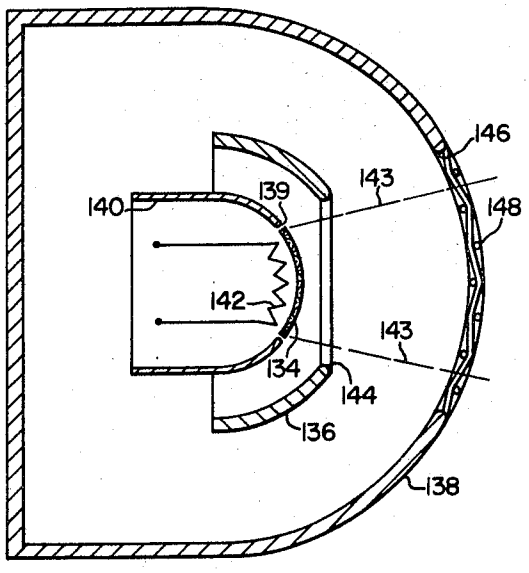


FIG. 12.

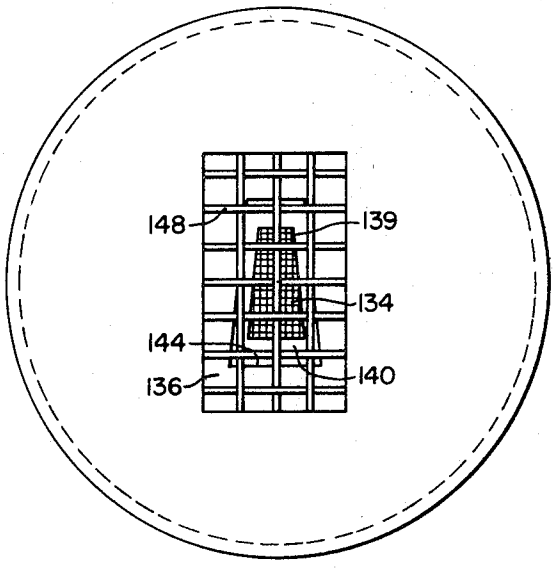
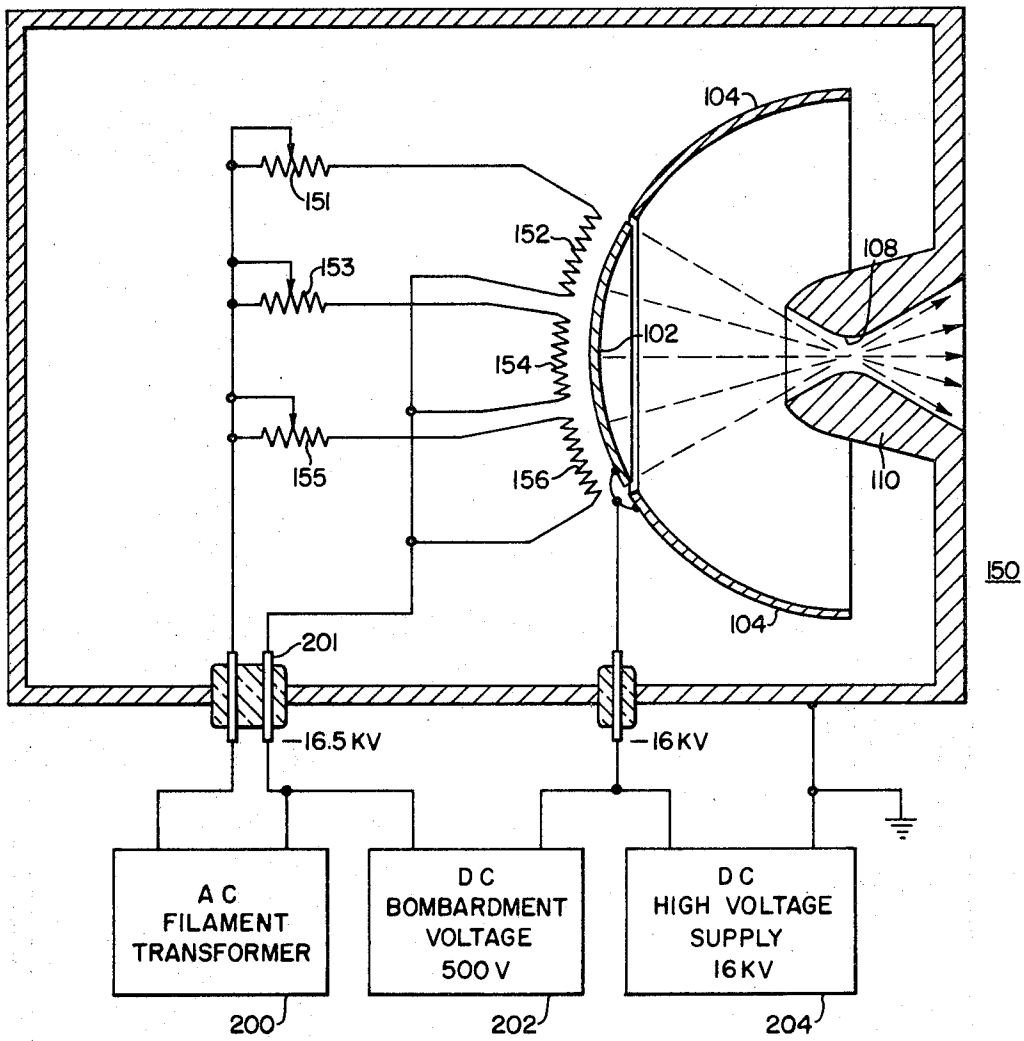


FIG. 13.


104
151
152
153
108
102
154
155
156
110
150
104
201
-16.5 KV
-16 KV
A C
FILAMENT
TRANSFORMER
200
D C
BOMBARDMENT
VOLTAGE
500 V
202
D C
HIGH VOLTAGE
SUPPLY
16 KV
204

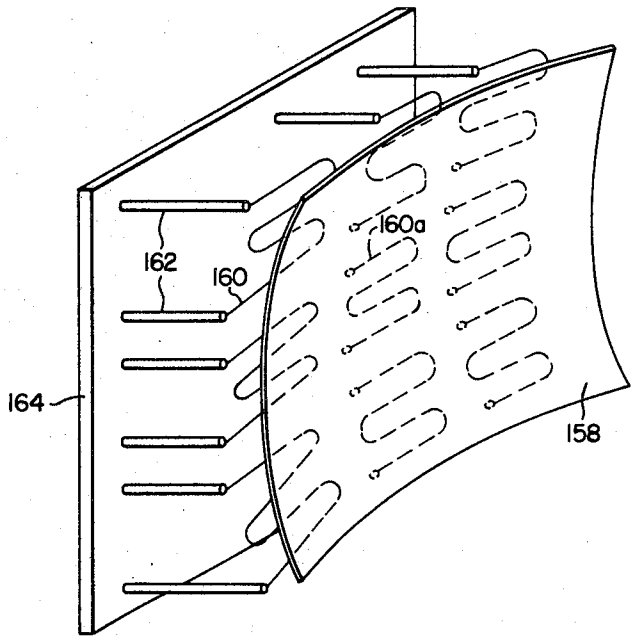

160a
162
160
164
158

FIG. 14.

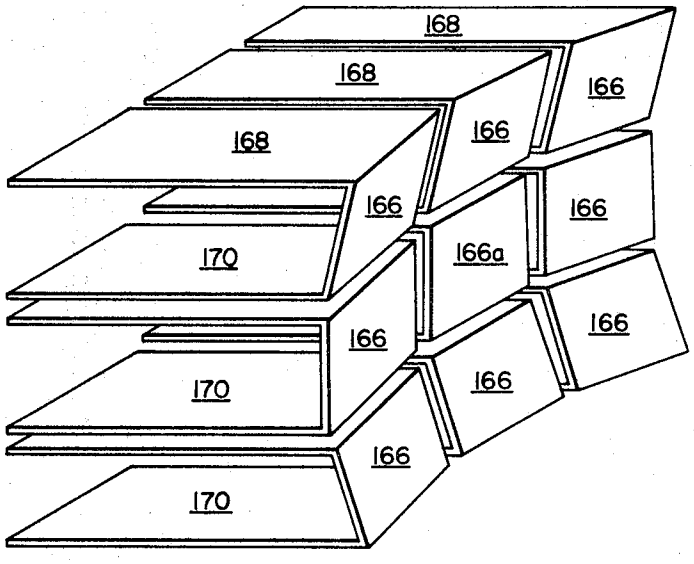

168
168
166
168
166
166
166a
170
166
166
166
170
166
170

FIG. 15.

COATING APPARATUS INCLUDING ELECTRON BEAM EVAPORATING MEANS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus for applying a coating on a substrate by vapor deposition and, more particularly, it pertains to means to apply a metal coating on a metal sheet by heating a body of the coating metal by high energy electron bombardment.

2. Description of the Prior Art

The processing of materials in high vacuum by electron-beam heating, which was little more than a laboratory curiosity a decade ago, has become an established large scale production method. An electron beam is a stream of electrons flowing from a cathode emitter and accelerated typically by a high voltage D.C. power supply. The stream of electrons can melt and evaporate a material when it strikes its surface, provided the beam contains sufficient energy to make up for the heat losses associated with holding materials at high temperatures.

Even though electron beam processing has become an established large scale production method, there has been a lack of activity in developing its potential in many areas. One problem involved with the operation of electron beams for evaporation melting of a material such as a metal surface is the difficulty of producing a reasonably uniformly heated surface and as a consequence producing a nonuniform distribution of coating on the coated product. One reason for the nonuniform or uneven coating is the electron pattern on the surface of the molten material caused in part by the diverging nature of the beam of electrons from its source until it strikes the evaporant surface. Another cause for uneven coating on a substrate is the variation in intensity of electrons across the cross-section of electron beams of some prior art devices. For example, the intensity of most electron beams is very high at the center and low in the peripheral areas.

One reason for the nonuniform or uneven coating is due to uneven heating of the melt because the cross-section of the electron beam as it impinges on the melt surface of the crucible does not match the shape of the melt surface. Nonuniform heating of the surface of the melt produces both localized agitation of the surface while other areas are much colder which results in nonuniform vaporization and resultant coating. As previously indicated, most electron guns produce a beam with a high electron density at the center and low density in the peripheral areas. Since the crucible loses heat more rapidly at the sides than at the center, a beam which has lower electron density at the center than at the periphery would be generally desirable to counteract this.

It is often desirable to deflect the electron beam by means of a magnetic field. Such a magnetic field may cause a focusing effect since, generally, such a field affects the trajectories of the electrons. For example, a beam that is bent 180° by a uniform transverse magnetic field will diverge as it leaves the gun but converge as it approaches the melt surface, in a plane at right angles to the magnetic field direction. In the other direction the beam will diverge all the way from the gun to the melt. Consequently, an initially round beam from a conventional electron gun may have an elliptical cross-section after it has been deflected by a magnetic field.

Associated with the foregoing is the problem of vapor or ion focusing of an electron beam due to the influence of molecules of the vaporized material as they rise through the zone above the molten surface where they confront the approaching beam of electrons. The problem is encountered in vaporizing of aluminum. As aluminum is vaporized, the vapor molecules rising from the vaporized surface confront the approaching beam of electrons, become ionized, and tend to constrict the electron beam and produce a high current density of smaller cross-section as it strikes the metal surface.

In accordance with this invention it has been found that the foregoing problems may be overcome by controlling the configuration of the cross-section and/or the intensity of electrons in various portions of the cross-section of a beam of electrons as it emanates from the source of the electron beam. The configuration of the cross-section of a beam of electrons is shaped to provide the desired pattern or cross-section of the beam as the beam strikes the surface to be vaporized. Likewise, the intensity of any portion of the cross-section of the beam may be varied by varying a corresponding portion of heating of the electron source in order to compensate for any portion of the vaporized surface which is over or under heated. The optimum beam geometry for a specific application depends upon the width of the substrate; the size, shape, and location of the crucible; the strength and distribution of the magnetic field; and the location of the electron gun system relative to the melt surface. Three controllable characteristics of the beam geometry are (1) the cross-sectional shape of the beam, (2) the current distribution within the beam, and (3) the divergence angle of the beam.

Accordingly, it is the general object of this invention to provide an apparatus for coating a substrate surface by vapor deposition by a uniformly heated coating metal.

It is another object of this invention to provide an apparatus for coating a substrate by vapor deposition by the use of electron beams having portions of its cross-section of greater or lesser electron intensity than other portions.

It is another object of this invention to provide an apparatus for applying a metal coating to a substrate by vapor deposition by the use of an electron beam the cross-section of which is controlled in order to compensate for the diversion of the beam from the source to the surface being evaporated.

It is another object of this invention to provide an apparatus for tailoring the beam geometry to achieve a desired temperature distribution at the surface of the melt.

Finally, it is an object of this invention to satisfy the foregoing objects and desiderata in a simple and effective manner.

SUMMARY OF THE INVENTION

Generally, the present invention involves a device for vapor depositing a metal coating on a metal substrate which metal coating is formed by bombarding the coating metal with an electron beam produced by means including a cathode and an anode the configurations of which are adapted to provide a desired pattern on the surface of the molten coating body, whereby a vapor having a uniform distribution of molecules of coating metal is applied to the substrate.

Moreover, the invention involves a process for applying a coating onto a substrate by vapor deposition comprising the steps of providing a container of the coating material to be vaporized in a sub-atmospheric pressure zone, projecting a beam of electrons from a source of electrons onto the coating material, modifying the geometry of the projected beam to conform with a specific pattern of vaporizable surface on the coating material, whereby the entire surface is heated and caused to vaporize.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the nature and objects of this invention, reference is made to the following detailed description and drawings, in which:

FIG. 1 is a diagrammatic view of a prior art construction;

FIG. 1A is a sectional view through the electron beam taken on the line 1A—1A of FIG. 1;

FIG. 2 is a vertical sectional view taken on the line II—II of FIG. 3;

FIG. 3 is a plan view of the construction shown in FIG. 2;

FIG. 4 is a vertical sectional view of one form of the invention taken on the line IV—IV of FIG. 5;

FIG. 5 is a plan view of the form of the invention indicated in FIG. 4;

FIG. 6 is a vertical sectional view through an electron gun taken on the line VI—VI of FIG. 7;

FIG. 7 is an end view of the gun shown in FIG. 6;

FIG. 8 is a vertical sectional view of a concave type of electron gun;

FIG. 9 is a sectional view taken on the line IX—IX of FIG. 8;

FIG. 10 is a perspective view showing schematically a single-cathode, multiple-beam type of electron gun;

FIG. 11 is a vertical sectional view of a convex type of electron gun;

FIG. 12 is an end view of the gun shown in FIG. 11;

FIG. 13 is a vertical sectional view through another type of concave electron gun;

FIG. 14 is an isometric view of a concave cathode for an electron gun; and

FIG. 15 is an isometric view of a segmented cathode for an electron gun.

Similar numerals refer to similar parts throughout the several views of the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In order to illustrate the invention, in FIG. 1 is shown a prior art crucible **10** containing a body **12** of a coating material such as aluminum metal to be evaporated, disposed directly below a substrate **14** such as a metal strip or sheet, which is to be coated by vapor deposition of the material in the crucible. For that purpose an electron gun **16** emits a diverging beam **18** of electrons toward the surface of the substrate **14**. The foregoing crucible, electron gun, and substrate are enclosed within an air-tight container **22** which is evacuated by vacuum pump means **24**.

The electron gun **16** is so disposed with respect to the crucible **10** and the substrate **14** that the electron beam **18** is directed in straight lines once it leaves the gun onto the surface of the metal body **12**. The cross-sectional area (FIG. 1A) of the beam **18** indicates that the electrons are dispersed in a substantially oval cross-section on the surface of the metal body **12**. The lower side of the beam **18** strikes the surface of the metal body **12** before the upper side of the beam which travels further. Because of the resulting greater dispersion of electrons the pattern of the beam **18** has a configuration substantially equal to an oval. As a result the surface of the metal body **12** is not uniformly heated by electrons, thereby resulting in a nonuniform evaporation of metal molecules and providing a coating on the substrate **14** which is uneven in some areas and heavier in others. A larger crucible tends to produce a more uniform coating but it is inefficient because a great deal of heat is lost by radiation. A greater distance from crucible to the substrate tends to produce a more uniform coating but this is inefficient because much of the evaporated metal does not hit the substrate. Consequently, it is most important to be able to employ the smallest possible crucible and to heat it with an electron beam having a desired set of characteristics.

In FIG. 2 another type of apparatus for vapor deposition of a metal is shown and differs primarily from that of FIG. 1 in that an electron gun **26** provides a beam of electrons having outer limits **28** and **30** which are projected in on a helical path through an angle of about 270° onto the surface of a metal body **32** within a crucible **34**. The electrons within the beam limits **28** and **30** are bent by a uniform magnetic field provided by a pair of spaced electromagnetic coils **36** and **38** (FIG. 3) such as Helmholtz coils of conventional construction.

The coils **36** and **38** produce a reasonably uniform field in the entire region through which all of the electrons travel. Since all of the electrons leave the electron gun with the same velocity, they will all follow a helical path of the same radius R as shown in FIG. 2. The gun **26** is located so that the effective center **25** of each diverging beam of electrons is located a distance R to the right of the center line of the melt and a distance R below the surface of the melt **32**. A right-hand lip **33** of the crucible **34** is located directly above the gun center **25**. With this particular arrangement the cross-section of the beam is quite narrow as it passes over the lip **33** of the crucible **34**, but is broad when it strikes the surface of the melt **32**. The surface of the melt is maintained at that level by an aluminum wire feed (not shown) of the type commonly used in the art.

Aluminum vapor travels in substantially straight lines from the surface of the melt so that most of the aluminum vapor impinges on the steel sheet, while most of the other vapor will hit the inside walls of the crucible **35** where it will condense and roll back down into the melt. High end walls **37** on the crucible minimize the loss of metal at the two edges of the steel sheet. Consequently, with this construction there is a minimum of wasted aluminum. As the electrons strike the metal body **32** the latter is melted and molecules of metal vapor **40** are directed upwardly to coat the undersurface of a substrate **42** which is preferably moved in the direction of an arrow **44** to provide a continuous operation.

Patterns of bombarded surface areas **50** and **52** of the metal body **32** are shown in FIG. 3. Where a pair of similar guns **26** are used a pair of adjacent bombarded areas **50** and **52** are provided, so that substantially the entire surface area of the metal body **32** is evaporated. As shown the areas **50** and **52** are rectangular and adjacent to each other because the guns **26** have been designed in a manner to be described hereinbelow in order to produce the desired beam pattern. As a result a substantially uniform evaporation of the surface of the metal body **32** occurs whereby an even metal coating is applied to the substrate **42**.

With two guns used in the manner shown in FIGS. 2 and 3, the bombardment of the aluminum surface **32** may be uniform at low temperatures but ion focusing at high vapor densities will cause each of the two electron beams to contract as they pass through the aluminum vapor. To over come this difficulty a procedure, as shown in FIGS. 4 and 5, can be used. A bank of a plurality of electron guns such as three rows of guns extending the length of the crucible is used. Although ion focusing will cause each of the beams of the guns to contract slightly, the temperature distribution in the melt is maintained substantially uniform. This results in a smooth molten surface and even evaporation, as compared with high concentrations of electrons on a molten surface which produce a turbulent melt surface and poor uniformity of evaporation. The guns **26** of FIGS. 2 and 3 may include a bank of two or more rows of guns **54**, **56**, **58**, **72**, **74**, **76**, shown in FIG. 5.

Rectangular electron beams **60**, **62**, and **64** from guns **54**, **56**, and **58** bombard three adjacent areas **66**, **68**, and **70** across the surface of the molten body **32** as shown in FIG. 5. Similarly, guns **72**, **74**, and **76** bombard areas **78**, **80**, and **82**. By providing three rows of guns that extend the full length of the crucible substantially the entire surface of the molten aluminum **32** is bombarded. Moreover, the current in any one gun or group of guns may be provided with the desired heating pattern. Since more heat is lost at the end of the crucible than at the center, the current in the end guns **54**, **56**, and **58** is normally adjusted higher than guns **72**, **74**, and **76**.

Various types of electron guns are shown in FIGS. 6 to 15 for use as sources of electrons in the several embodiments for electron vapor deposition as shown in FIGS. 1 to 5. In FIG. 6 an electron gun **84** includes a cathode **86**, a focus grid **88**, and an anode **90**. The cathode **86**, which is disposed between a pair of terminals **92** connected to a power supply, is constructed of a suitable material such as tungsten, tantalum, rhenium, and hafnium for emitting electrons **94** in a manner well known in the art.

The anode **90** and the focus grid **88** are provided with apertures **96** and **97**, respectively, of such shape as to produce the beam **94** having the desired cross-sectional shape and current distribution. For example, the aperture **96** has a trapezoidal shape with a narrow upper end **98** and a wider lower end **100**, and the aperture **97** is trapezoidal. The electrostatic field between the two trapezoidal openings yield the beam **94** having substantially a trapezoidal cross-section. The current distribution within the beam is dependent upon the relative sizes of the anode aperture **96**, the grid aperture **97**, and the cathode **86**, the distance **99** between the cathode **86** and the grid opening **97**, and the distance **101** between the grid opening **97** and the anode opening **96**.

It has been found that a gun of this type will not only produce the desired beam shape, but the electron density around the periphery of the beam can be made greater than that in the center when this is desirable. Where the gun **84** is used in the construction of FIG. **1**, the upper portion of the beam **18**, which disperses more than the lower portion (due to a greater distance of travel), passes through the narrower upper end portions of the trapezoidal apertures in the anode and grid, thereby adjusting the beam cross-section to provide a rectangular pattern on the surface **12**.

In a similar manner if the electron gun **84** were substituted for the gun **26** in FIG. **2** the outer portion of the beam **30** would then project further, or travel a greater distance than the inner portion **28**. For that reason the lower portion of the anode aperture **96** is narrower to compensate for the longer travel of the portion **30** than the portion **28**. As a result a rectangular beam pattern is disposed on the surface of the metal body being evaporated.

Another type of electron gun is shown in FIGS. **8** and **9** in which a concave cathode **102** is centrally disposed within a grid **104** for directing a beam **106** through an aperture **108** in an anode **110**. The cathode **102** and the grid **104** form a concave cathode-grid assembly with the cathode **102** being centrally disposed and connected to a pair of terminals **112** which is heated to a temperature of about 2800°K.

The cathode **102** is heated by passing current through it. The anode **110** is at ground potential and the cathode is at a large negative potential (−10 to −30 kV). The grid **104** is at a potential of (0 to −300 volts) relative to the cathode. One mode of operation is to connect grid **104** to one of the cathode terminals **112** by a lead **114**. The electric field between the cathode **102** and the anode **108** is essentially radial so that electrons are accelerated through the aperture **108** of the anode **110**.

As shown in FIG. **9** the cathode **102** has one end **116** wider than a lower end **118** to provide a truncated spherical segment for directing the beam **106** so that the final cross-section of the projected beam is rectangular on the vaporized surface.

Where a plurality of two or more sources of electron beams are desirable, the number of electron guns, such as those described in FIGS. **6** and **8**, are used to provide the desired number of beams. Alternatively, a linear gun **120** (FIG. **10**) may be used, whereby a plurality of separate beams are provided by one gun. The gun **120** includes an outer housing or anode **122**, a focus grid **124**, and a single elongated cathode or wire **126**. The anode **122** and grid **124** are preferably rectangular in cross-section with the grid disposed within the anode. The cathode or wire **126** is linearly coextensive with the anode and grid. The anode **122** includes a plurality of longitudinally spaced apertures **128**. Likewise, the grid **124** includes a plurality of longitudinally spaced apertures **130** which are aligned with the apertures **128**.

In addition, the apertures **128** and **130** have a trapezoidal configuration so that electrons emanating from the single heated cathode **126** within the grid **124** pass through the apertures **130** and **128** and thereby have a trapezoidal cross-section. Thus, the separate beams of electrons emanating from the linear gun **120**, when subjected to a magnetic field such as that shown in FIG. **2**, are projected onto the surface of the metal body to be evaporated and provide a pattern which is substantially rectangular in a manner similar to the beams directed from the guns of FIGS. **6** and **8**. The surface of the metal body being evaporated is uniformly heated without overlapping or gap portions. In addition, the linear gun **120** may be used with the construction shown in FIGS. **4** and **5**, whereby the three guns **120** may be used in bank formation to provide the desired surface to be evaporated such as shown in FIG. **5**.

The size and spacing of the apertures **128** and **130** are adjusted to produce the desired current distribution at the crucible. For example, if more current is desired at the two ends of the crucible to compensate for the high heat loss at these points, the end apertures can be made longer, thereby increasing the beam current from these portions of the gun. An alternate arrangement for the gun shown in FIG. **10** is to employ a single long aperture slit for the anode in place of the series of trapezoidal openings.

Another type of electron gun **132** is shown in FIGS. **11** and **12**. It includes a cathode **134**, a focus grid **136**, and an anode **138**. The cathode **134** is a sheet-like member of convex configuration enclosed in an opening **139** within a dome-like support member **140**. The cathode **134** is heated by a filament **142** which is disposed on the side of the cathode remote from the grid **136**. An electron beam **143** emanates from the cathode **134** and is directed through a trapezoidal aperture **144** in the grid **136** and thence through an aperture **146** in the anode **138**. As shown in FIGS. **11** and **12** the aperture is covered with a wire mesh **148** to achieve a radial electrostatic field geometry.

The gun may operate with no focus grid **136**. However, when such a grid **136** is used and a lead is brought out to an adjustable voltage d-c power supply, some control of the beam size can be achieved by varying the voltage on the grid **136** because this will modify the radial field between grid **134** and anode mesh **148**.

As shown in FIG. **12**, the cathode **134** has a trapezoidal configuration in a manner similar to the convex cathode **102** (FIG. **9**). That configuration of the cathode provides an electron beam **143** having a cross-section which, when bent through an arc of up to 270° in a manner as shown in FIG. **2**, provides a pattern of evaporation surface on a metal body which is rectangular and thereby conforms with the entire or partial portion of the metal surface body.

In FIG. **13** another type of electron gun **150** having a concave configuration and other parts similar to that of the gun shown in FIGS. **8** and **9** for which reason similar parts are similarly identified to simplify description. The cathode **102** is heated by electron bombardment from a plurality, such as three, separate filaments **152**, **154**, and **156** disposed on the side of the cathode opposite the anode **110**. By varying the temperature of each filament **152**, **154**, and **156** the intensity of electrons emanating from any surface portion of the cathode **102** may be varied over its surface. Accordingly, in addition to providing the cathode with a specific configuration such as a trapezoid as set forth hereinabove the source of electron beam, namely the cathode **102**, is heated to different temperatures in various portions so that the intensity of electrons striking the surface of the metal body to be evaporated is greater in some areas than in others. For example, the outer extremities of the pattern of the beam as it strikes the metal surface may require more electrons than the inner portion of the pattern, because of the greater amount of heat lost by the outer extremities adjacent to the crucible. For that reason the center of the cathode **102** may be heated to a lesser degree by the filament **154** (FIG. **13**) than are the peripheral portions of the cathode.

Potentiometers **151**, **153**, and **155** are used to control the temperatures of filaments **152**, **154**, and **156**, respectively. Three sources of electric power **200**, **202**, and **204** are required for the gun. The a-c filament supply **200** supplies power to all the filaments in parallel. Since the secondary is at a high negative d-c voltage it must have high voltage insulation. The unit **204** is a high voltage d-c supply (−10 to −30 kV) which has its positive terminal grounded and its negative terminal connected to the cathode **102**. The unit **202** is a d-c bombardment supply with an output of 0 to 500 volts. The positive terminal is connected to the cathode **102** and the negative terminal is connected to the common filament terminal **201**.

The principle of heating different portions of the cathode to different temperatures is further disclosed in FIG. **14** in which a cathode of any configuration such as concave **158** composed of sheet material is heated by a plurality of spaced heating filaments **160** of similar construction. Each filament **160** is mounted on the extremities of a pair of similar conductors **162** extending from an insulating support member **164**. Thus, if it is desirable to heat the center portion of the cathode **158** to a

greater or lesser extent than any other portion in order to intensify or reduce the number of electrons in the beam, the particular filament **160***a* is heated to a greater or lesser extent than the surrounding filaments **160**.

A further form of the invention is shown in FIG. **15** in which a plurality of spaced sheet-like segments **166** provide a cathode for transmitting a beam in a manner similar to electron beams created by the other cathodes described above. The cathode segments **166** are individually heated by current flowing through each segment via conductor portions **168** and **170**, whereby the intensity of each segment **166** is varied in accordance with requirements. It is desirable to reduce the number of electrons in the center of a beam emanating from the assembly of cathodes for which reason a center cathode segment **166***a* is heated to a lesser temperature than the temperatures of the surrounding cathode segments.

Accordingly, the device of the present invention provides an electron beam producing means in which either the cathode or the anode housing or both are modified to provide an electron beam having a configuration which projects a specific geometric pattern of electrons on the surface of the metal body to be vaporized. Moreover, the cathode may be heated to varying temperatures to provide a greater or lesser amount of electrons in a specific area of the electron beam as required on the surface of the metal body being evaporated.

In the examples given an electron beam of trapezoidal cross-section was given in order to produce a rectangular pattern on the surface of a rectangular crucible containing molten aluminum. In some applications other shaped crucibles will be desirable and so other beam cross-sections will be desired. For example, if a round crucible is used then an elliptical (or oval) cross-section will be desirable.This can be achieved using the teachings of this disclosure by substituting elliptical cathodes, focus grids and anode apertures in place of the trapezoidal shapes.

Although the invention described was concerned with the continuous evaporation of aluminum onto moving steel sheet the same apparatus can be applied to the evaporation of aluminum onto other substrates and to the evaporation of other materials onto a variety of substrates.

Various modifications may be made within the spirit of the invention.

I claim:

1. An apparatus for vapor depositing a coating on the surface of a substrate passing over a crucible of a molten material to be so vapor deposited, comprising an evacuated enclosure, a crucible disposed in the enclosure and containing a body of the given material which in the molten state assumes a given melt surface configuration, means for supporting and passing the substrate over the crucible and providing a predetermined small space between one lip of the crucible and the substrate, electron beam producing means within the enclosure and disposed below the crucible with the axis of at least one electron-emitting cathode being on a line generally vertically below said one lip, a housing about said cathode, the housing having an aperture in alignment with respect to the cathode such that the alignment is at an angle of about 300° to 240° to a vertical line to the surface of the molten material whereby substantially no vapors of molten material tend to enter the aperture, and magnetic field producing means disposed transversely of the crucible and the electron beam producing means, the magnetic field means causing an electron beam passing through the aperture to be converged and directed radially to pass substantially entirely through the predetermined space between the said one lip of the crucible and the substrate and thereafter diverged so as to impinge on effectively all of the melt surface configuration whereby to produce relatively uniform heating of the molten metal and to effect efficient and uniform deposition of vapors of the material on the substrate, said one cathode being of generally concave configuration and comprising a plurality of sheet-like segments spaced from one another, each segment combined with a separate heater element whereby the electron beam emitted by each said segment is individually controlled and whereby the emitted electron beam of said one cathode may be varied in intensity across the transverse section thereof; and the housing comprising an apertured concave grid concentric to and complementary to the concavity of said one cathode and an apertured anode centrally disposed with respect to the cathode-grid assembly, the cathode and the aperture defining portions of the grid and cathode being peripherally configured to facilitate impingement of a predetermined beam pattern conforming to said metal surface configuration.

2. The apparatus of claim **1** for coating an elongated substrate moving linearly over a crucible, the crucible providing a rectangular melt surface of coating material, and at least one electron beam gun directing a rectangular impingement pattern on the melt surface.

3. The apparatus of claim **1** wherein the electron-emitting cathode and the housing apertures having a trapezoidal configuration, and the magnetic field-producing means providing a field that is transverse to and coextensive with the path of travel of the electron beam from the beam producing means to the melt surface.

4. The apparatus of claim **3** wherein the electron beam travels through an arcuate diverging path from the beam producing means to the melt surface and terminates on the melt surface in a rectangular pattern.

5. The apparatus of claim **1** in which the electron beam emanating from the gun is a divergent beam including an outer peripheral beam portion directed about a center of rotation toward one zone of the melt surface and including an inner peripheral beam portion directed about a center of rotation toward another zone of the melt surface, the beam also including beam portions between the inner and outer beam portions directed in a similar manner to intervening zones on the melt surface, and all of the beam portions in their path of travel providing a wide beam at the melt surface and providing a narrow beam at the predetermined space between the lip of the crucible and the substrate.

6. The apparatus of claim **1** wherein the electron beam producing means includes at least two electron beam guns.