March 11, 1969 S. SCHILLER ET AL 3,432,335

CYCLICALLY MOVING ELECTRON BEAM FOR UNIFORM VAPOR DEPOSITED COATING

Filed July 19, 1966

FIG. 1

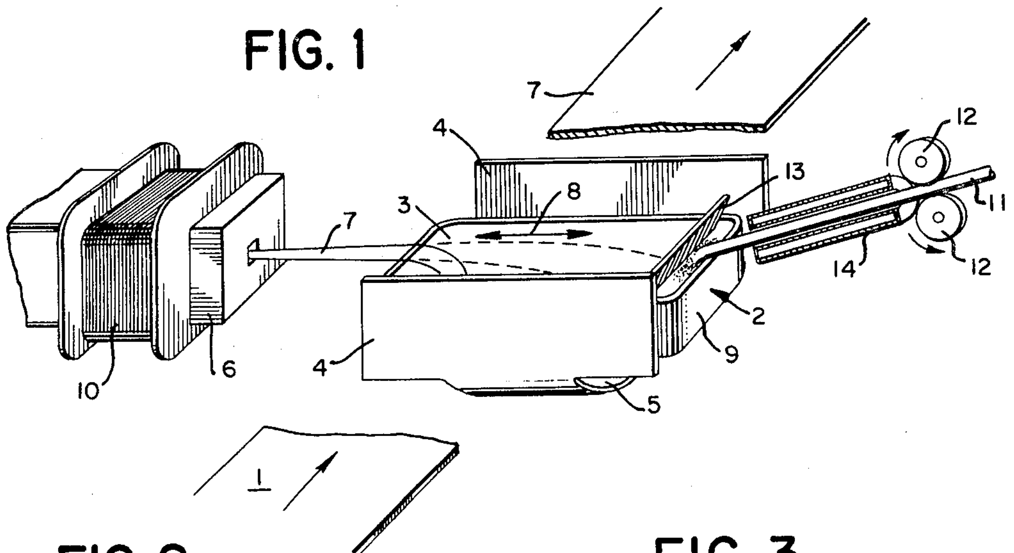


FIG. 2

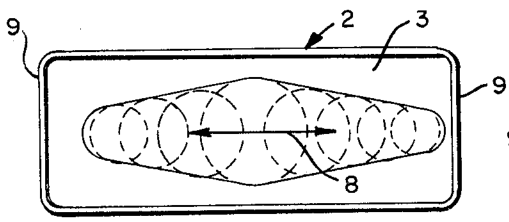


FIG. 3

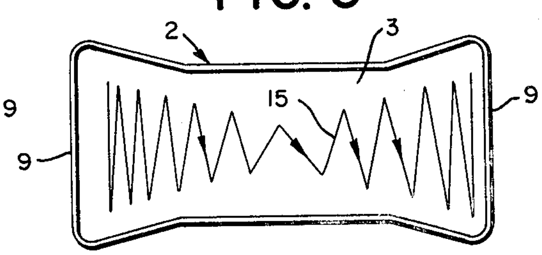
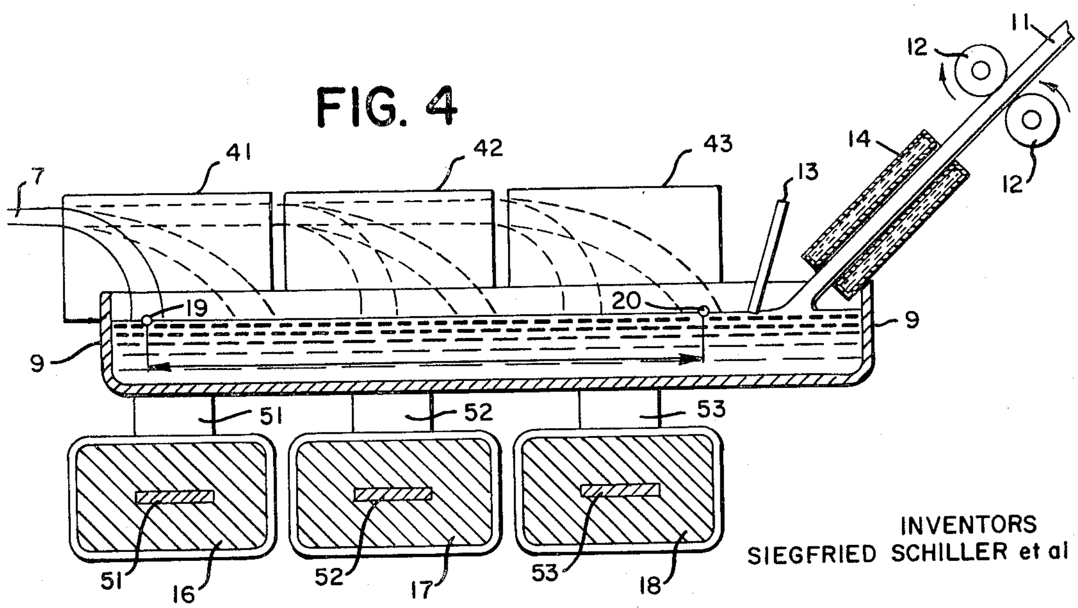


FIG. 4



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CYCLICALLY MOVING ELECTRON BEAM FOR UNIFORM VAPOR DEPOSITED COATING

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Int. Cl. C23c 13/02, 13/08

ABSTRACT OF THE DISCLOSURE

A method for vapor depositing in a vacuum a uniform coating onto a substrate by cyclically deflecting and moving an electron beam onto a surface of the coating material held in a container to vaporize the material whereby the electron beam is maintained for longer periods of time in the ends of the container than in an intermediate portion situated between the container ends.

The present invention relates to a method and apparatus for the vapor-deposition, in an evacuated atmosphere, of relatively large surface areas, such as, for example, a face of a relatively wide band during movement of the latter, this band or other work being made of metal or other materials.

Methods for vapor-deposition in evacuated atmospheres have long been known. For the heating of the material which is to be vaporized it is known to use either indirect or direct heating of material situated in a suitable container, such as a suitable crucible. The heating takes place either by way of passage of an electric current through the material or inductively.

It is also known to use, as a heat source, electron or ion beams. In the most recent times, vaporization by means of electron beams have become of great significance. Methods which involve the use of electron beams for heating purposes are indeed more expensive than previously known methods, but they are of advantage because they are capable of providing a high concentration of energy which makes it possible to provide relatively fast rates of vaporization over relatively large areas, so that a large output can be achieved through such methods. Moreover, by using water-cooled copper containers for the material which is to be vaporized, it is possible to vaporize metals which have a high melting point and which would react with other materials.

In recent times it has become especially important to be able to provide in an evacuated atmosphere vapor-deposition of relatively large surface areas so as to improve the latter. A particular technical problem which is encountered is the achievement under these conditions of a uniform thickness of the layer of vaporized material on the work which receives the layer. In order to achieve a uniformly thick vapor-deposited layer on a relatively wide band, it is known to use several containers for the material which is to be vaporized and to alternately direct an electron beam into these containers.

Moreover, it is known, for the purpose of vapor-deposition of relatively wide bands, to arrange a plurality of the containers for the material which is to be vaporized and a plurality of sources for relatively flat electron beams between magnetic pole plates, the plurality of containers and the plurality of electron-beam sources being distributed across the width of the band which is to receive the vapor-deposited layer. The bundle of electrons must, with such an arrangement, be deflected through approximately 180°.

These known constructions have the disadvantage of

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being very costly and moreover the properties of the layers which are achieved do not have the best possible characteristics, particularly with respect to the homogeneity of the structure of the vapor-deposited layer.

Morover, these known structures have the disadvantage of being capable of providing a uniform layer only under conditions where the distance between the container for the material which is vaporized and the work which receives the vapor-deposited layer is maintained relatively large as compared to the size of the work which is to receive the vapor-deposited layer. As a result the vaporized material is utilized to only a small extent. A reduction in the space between the work and the container for the vaporized material results above all in highly significant changes in the properties of the layer, in particular in the thickness and homogeneity of the layer, especially at the regions of the outer side edges of the work. In the latter side-edge regions of the work only a relatively small percentage, in general, of the vaporized material will be deposited on the work. When vapor-depositing relatively large areas and wide bands, which preferably have a width of greater than one meter, it is therefore not advisable to use the above methods. Where an extremely small source of vapor is used to deposit the layer in localized areas on the work, the thickness of the deposited layer will depend upon the size of the area which is vaporized, the temperature of the material which is vaporized, the distance between the source of vapor and the localized area of engagement of the vapor with the work, and upon the angle between a line normal to the surface of the vaporized area of the material which is vaporized and the vector which extends between the source of vapor and the localized area of engagement between the vapor and surface which receives the vaporized layer. Even if the container for the vaporized material is elongated so as to correspond to the width of the work which is to be vaporized and the temperature of the vaporized material is maintained constant over the entire surface area of the material which is to be vaporized, the edge regions of the work receive a layer whose thickness is less than the remainder of the layer. The reason for this phenomenon resides in the fact that the edge regions of the work have a greater distance from the individual points of the upper surface of the vaporizable material than the intermediate regions of the work.

It is therefore a primary object of the present invention to provide a method and apparatus capable of vapor-depositing relatively large surfaces in a vacuum, even if the surface of a moving band is involved, while maintaining a homogeneous vapor-deposited layer together with a high rate of vapor-deposition and at the same time capable of providing a relatively small distance between the container for the vaporizable material and the work which is to receive the vaporized layer.

Thus, it is an object of the invention to provide a process and apparatus which will avoid the drawbacks of the present state of the art.

It is in particular an object of the invention to provide a method and apparatus which make it possible to achieve a rate of vaporization, in the region of the ends of the container for the vaporizable material, which is not only adjustable but which also is greater than the rate of vaporization of the vaporizable material at an intermediate region of the container, situated between the end regions thereof.

Primarily, with the method and apparatus of the invention an electron beam which is angularly distributed in a symmetrical manner about a predetermined axis is horizontally projected into the space between the downwardly directed surface of the work and the open top of an elongated container for the vaporizable material, this elongated container extending transversely across the work beneath the latter and having a length corresponding substantially to the width of the work. Thus, when the work is, for example, a longitudinally moving band the ends of the container will be situated beneath the side edge regions of the band, and the space between the work and the container need only be great enough to permit the electron beam to enter horizontally between the container and the band. The electron beam is magnetically deflected down into the container to engage the vaporizable material therein, and this deflection of the magnetic beam is cyclically carried out according to the process of the invention in such a way that the beam engages the vaporizable material along a path which moves back and forth along the container, the programming of the cyclical deflection being such as to maintain the beam for longer periods of time in the regions of the ends of the container than in an intermediate region thereof situated between its ends.

The invention is illustrated by way of example in the accompanying drawings which form part of this application and in which:

FIG. 1 is a fragmentary, perspective, schematic illustration of one possible embodiment of a structure according to the invention for carrying out the process of the invention;

FIG. 2 is a schematic top plan view of the container for the vaporizable material, FIG. 2 showing schematically the manner in which the electron beam is cyclically displaced along the container;

FIG. 2 illustrates, in a schematic top plan view, another embodiment of a container of the invention for the vaporizable material, FIG. 3 also schematically illustrating another method for cyclically moving the electron beam along the surface of the vaporizable material; and

FIG. 4 is a schematic longitudinal sectional elevation of another embodiment of an apparatus of the present invention for carrying out the method of the present invention.

In the illustrated example, as shown in FIG. 1, the work which is to receive the vapor-deposited layer is in the form of an elongated continuously moving band **1**. However, it is to be understood that it is also possible to provide, in accordance with the invention, vapor-deposition on any large surface made up, for example, of a plurality of individual smaller surfaces which are combined together to form a relatively large surface. With the process and apparatus of the invention the vapor-deposition takes place with great accuracy and at high intensity. The work **1**, which may be any material, such as, for example, steel or iron, or even plastic or textiles, is to receive a protective layer, by vapor-deposition, on one or both sides, and this vapor-deposited layer is composed of a predetermined metallic material. For this purpose the work **1** travels at a relatively small distance from an elongated container **2**, in the form of a crucible for the material which is to be vaporized, this container **2** having an open top and being situated directly beneath the work **1**. Within the container **2** is situated the material **3** which is to be vaporized. The length of the container **2** corresponds approximately to the width of the band **1**, and the container **2** is situated symmetrically beneath the band **1** so that the ends of the container **2** are at least approximately in alignment with the opposed side edges of the work **1**. It is possible, however, for the container **2** to have a length somewhat greater than the width of the band **1**, although, because of the particular advantages which can be achieved by way of the present invention it is also possible to provide a container **2** whose length is somewhat shorter than the width of the band **1**. The width of the container **2** is of only secondary importance. In most cases the container **2** will have a rectangular configuration, as indicated in FIG. 2.

Situated along the opposed longitudinal sides of the

container **2**, so as to extend transversely to the direction of movement of the band **1**, are pole shoe plates **4**. Between these plates **4** is located a magnetic field. The pole shoe plates **4** are interconnected by means of a magnetic yoke **5** which is situated beneath the container **2**. A coil is arsranged on the yoke **5**, and an adjustable current flows through this coil so as to provide the magnetic flux and thus the magnetic field. The coil carried by the yoke **5** is not illustrated in the drawing.

Adjacent one end of the container **2** is situated an electron beam producing means **6** in the form of a suitable electron gun which provides an electron beam **7** which is of a symmetrical cross section with respect to a central axis extending longitudinally along the electron beam **7**. This electron beam **7** is directed transversely to the direction of movement of the work **1** and thus transversely to the magnetic field. The beam **7** is projected horizontally between the pole shoes **4**. The magnetic field acts to deflect the electron beam **7** onto the vaporizable material **3** within the container **2**, and it is downwardly through the open top of the container **2** that the beam **7** is deflected by the magnetic field.

By changing the voltage or the current at or in the coil which is carried by the yoke **5**, the intensity of the magnetic field is changed, so that different radii of deflection for the electron beam **7** can be provided. This operation is illustrated in FIG. 1. Thus, the electron beam **7** is directed longitudinally of the container **2** and therefore longitudinally along the vaporizable material **3**, engaging the top surface thereof. The programming of the variation of the electrical energizing of the coil carried by the yoke **5** is such as to produce a cyclical, periodically repeating travelling of the beam **7** longitudinally back and forth along the upper surface of the material **3**, as indicated by the double-headed arrow **8** in FIGS. 1 and 2. By periodically and cyclically changing the current or the potential in or at the coil, the manner in which the beam **7** moves back and forth along the material **3** is precisely controlled. Thus, the coil carried by the yoke **5** is situated in an electrical circuit so as to be energized according to a cyclical program which periodically repeats itself so as to provide a predetermined, periodically repeating program of deflection of the beam **7** downwardly onto the material **3**, travelling back and forth along the latter.

The electron beam can be regulated in this way so that the time during which it remains in the region of the ends **9** of the container **2** will be longer than the time that the electron beam remains in the region of an intermediate portion of the container **2**, between its ends **9**. As a result it is possible to provide at the end regions **9** of the container **2** localized areas of a temperature higher than the temperature of the vaporizable material **3** at an intermediate region of the container **2**, and as a result of the maintenance of the higher temperature at the end regions **9** there is a greater vapor pressure at the end regions **9**. Inasmuch as the edges of the work **1** are situated also in these regions of higher vapor pressure, it is possible to achieve in this way an outstanding uniformity in the properties of the vapor-deposited layer with the properties thereof in the region of the edges of the band **1** being precisely the same as the properties thereof along an intermediate portion of the band **1** between its side edges. By programming the deflection of the beam **7** in the above manner it is possible to provide at the end regions **9** of the container **2** a temperature which may be up to 400° C. higher than the temperature of the vaporizable material at an intermediate region of the container **2**.

Furthermore, it has been found that the rate of vaporization and the homogeneity of the vapor-deposited layer depends upon the distance between the areas of contact of the beam **7** with the material **3** at the minimum and maximum deflecting radii of the beam **7**, which is to say how far the regions of the highest temperature are situated from a point midway between these regions of highest temperature in a direction transverse to the direction of movement of the band **1**. In this way it is possible to achieve a further adjustment of the thickness of the vapor-deposited layer on the work **1**. Since at extremely high rates of vapor-deposition a considerable scattering of the electron beam **7** in the vapor takes place and this scattering is greatest at the end region **9** which is distant from the gun **6**, and since in addition the concentration of heat from the electron beam is at a minimum at the region of the largest radius of deflection of the electron beam as a result of the distortion by the magnetic field as well as a result of the longer path for the electron beam and the scattering thereof, it is necessary to take corresponding measures to see to it that the above-mentioned temperature distribution is maintained. This latter result can be achieved by periodically changing the current excitation of a magnetic lens **10** in correlation with the program of periodic cyclical deflection of the electron beam **7**, or it is also possible to achieve this result by providing a nonsymmetrical program of periodic, cyclical deflection of the electron beam **7**, with respect to the center of the container **2**, so that the beam **7** will be maintained at the end **9** which is most distant from the electron gun **6** for a time greater than at the other end which is near to the gun **6**, thus compensating for the tendency of the material **3** at the end **9** which is distant from the gun **6** to cool as a result of the above factors. Thus, when resorting to this latter expedient the electron beam **7** will be maintained for the longest period of time, by suitable programming of the excitation of the coil carried by the yoke **5**, at the region where it has the largest radius of deflection. Attention is invited in this connection to FIG. 2 which diagrammatically illustrates this type of operation and which further shows by way of the circles of different diameters the manner in which the lens **10** can be operated so as to provide either highly concentrated localized areas of contact of the beam **7** with the material **3** at the region of the ends **9** and larger spreading of the area of contact of the beam **7** with the material **3** at an intermediate region of the container **2**.

As is indicated at the right portion of FIG. 1, the vaporizable material **3** is supplied to the container **2** in the form of a wire. Such a wire **11** is indicated in FIG. 1 as being delivered to the container **2**, at the end **9** thereof which is most distant from the electron gun **6**, by means of an adjustable feeding structure **12** which continuously feeds the wire **11** at a predetermined rate into the right end of the container **2**, as viewed in FIG. 1. In order to prevent any variation from the predetermined process of vapor deposition referred to above and also in order to prevent any harmful spraying of the molten liquid, the receiving region of the container **2**, which receives the wire **11**, is provided with a protective screen **13**, so that this region of the container **2** is screened off to prevent particles of metal from splashing or otherwise spraying undesirably either onto the work or onto other parts, such as the pole shoe plates **4**. At the region where the wire **11** extends into the molten bath of metal so as to become molten therein, there is a tendency for the material **3** to cool as a result of the amount of heat which must be supplied to this region as well as a result of the relatively low temperature of the wire **11**, and thus there is a tendency for the vaporizing temperature to be reduced at this region.

However, through suitable programming of the deflection of the beam **7** the tendency for this temperature loss to have an undesirable influence on the operation is opposed and precisely compensated, in an extremely simple manner, so that the precise carrying out of the process of the invention in the above-described manner can be maintained even though the wire **11** is continuously fed into the bath in the manner shown in FIG. 1 and described above. Thus, the periodic cyclical deflection of the beam **7** will be carried out in such a way that in the region where the wire **11** is supplied to the container **2**, this beam **7** will remain for a longer time than at other regions, and the required high temperature at the region where the wire **11** joins the material **3** can be maintained.

This wire **11** can, for example, be fed to the container **2** while passing through a water-cooled tubular guide **14**, as shown schematically in FIG. 1.

A further possibility for enhancing the homogeneity of the vapor-deposited layer resides in widening of the upper surface of the material **3** at the region of the ends **9** of the container **2**, and such a construction is shown in FIG. 3. Furthermore, there is the possibility of periodically and cyclically deflecting the electron beam not only longitudinally of the container **2** but also transversely thereof, and this operation is schematicaly indicated by the zig-zag path **15** indicated in FIG. 3. Thus, when the end of the beam **7** which engages the material **3** is moved along the path **15** shown in FIG. 3 there will be, in addition to the above-described longitudinal beam deflection along the container **2**, a beam deflection transversely with respect to the container **2**, in the same direction that the work **1** moves. In order to bring about deflection of the beam **7** along the path **15**, for example, it is only required to arrange between the electron gun **6** and the container **2** a magnetic deflecting system which, in a well known manner, will provide predetermined amplitudes of deflection of the beam.

One of the factors which determines the temperature of the material **3** at any given region of the container **2** is the concentration of the electron beam **7** at the area where it contacts the material **3**. In other words, assuming that a constant electron beam **7** is provided, the temperature at any given region of the material **3** will be determined by the area of contact between the beam **7** and the upper surface of the material **3**. Moreover, the magnitude of this area of contact of the beam **7** with the upper surface of the material **3** is determined by the angle at which the beam **7** is directed downwardly onto the material **3**, or in other words by the angle between the electrons and the upper surface of the vaporizable material. As may be seen from FIG. 1, the angle between the beam **7** and the vaporizable material in the region of the end **9** of the container **2** which is nearest to the electron gun **6** approaches 90°, so that relatively small area of contact will form, while in the region of the screen **13**, or in other words at the end region **9** which is most distant from the electron gun **6**, the angle between the beam and the surface of the vaporizable material is considerably smaller than 90°, so that the area of contact is much greater than at the end region **9** which is nearest to the electron gun **6**.

It is therefore desirable to be able to maintain along the entire surface of the vaporizable material **3** an angle of engagement between the beam and the surface of the material **3** which is as uniform as possible, so that in this way it will be possible to have precsely the same areas of contact of the electron beam **7** wth the vaporizable material at all parts of the container **2**. In order to achieve this result it is possible to divide the magnetic field which deflects the electron beam **7** into a plurality of individual magnetic fields which are separately excited. Such a construction is illustrated in FIG. 4. In this embodiment instead of single pole shoe plates **4** which extend along the entire length of the container **2**, there are three pole shoe plates **41, 42, 43** situated along one side of the container **2** and three identical pole shoe plates situated at the opposite side of the container in alignment with the plates shown in FIG. 4, so that in fact there are three pairs of aligned pole shoe plates distributed along the container **2**. In this embodiment individual yokes **51, 52, 53** interconnect the pairs of pole shoe plates **41, 42, 43**, respectively. The individual magnetic fields are derived from the individual coils **16, 17, 18**, indicated in FIG. 4.

The periodic cyclically varying current which flows through the coils **16, 17, 18** have with respect to each other a predetermined phase shift, so that the deflection of the electron beam **7** will take place in the manner indicated in FIG. 4. For example, if the current in the coil **16** is diminishing, so that the intensity of the magnetic field between the pole shoe plates **41** is dropping off, then at the same time the current in the coil **17** is increasing so that the intensity of the magnetic field between the pair of pole shoe plates **42** is increasing. The current flowing through the coil **17** is at its maximum when the current flowing through the coils **16** and **18** has diminished to such an extent that at that particular instant there is no current flowing through the coils **16** and **18**.

In this way the electron beam **7** travels from the position **19**, shown at the left in FIG. 4, to the position **20**, while having an almost entirely uniform area of contact and angle of engagement with the material **3**.

It is often also required to vapor-deposit, at the same time, several different materials, to achieve a predetermined vapor-deposited alloy, or it is required to vapor-deposit different materials one after the other to provide a vapor-deposited layer made up of a plurality of individual sublayers of different materials. With the present invention it is possible to achieve these latter results in an extremely simple way. In one such case, for example, a pair of containers **2** are arranged one beside the other, so that each of these containers can be provided with its own particular vaporizable material. The vaporizing temperature and the vapor pressure of the individual materials in a pair of such containers can be completely different. The electron beam **7** in such a case is alternately deflected into the different containers and can be brought into contact with the different vaporizable materials according to completely separate and completely different cyclical porgrams of deflection suitable for the particular materials, respectively. Thus, the program of deflection of the electron beam can be adapted in the one case to the particular properties of the material in one container and in the other case to the properties of the material in the other container, so that in this way it is possible to achieve vapor-deposted layers having predetermined properties.

It is thus possible with the present invention to take into consideration all of the various parameters which will determine the properties of the vapor-deposited layer, in accordance with the desired end properties of the vapor-deposited layer, so that in this way it is possible to influence the vapor-deposition in such a way that a precise control is provided to achieve, in a highly accurate manner, a vapor-deposited layer of predetermined properties.

It is to be noted, as shown at the end regions **9** of the container **2** of FIG. 2, that by way of the magnetic lens **10**, which is of a conventional construction, it is possible to control the cross sectional area of the electron beam **7** so that while the total energy thereof remains the same, this energy can be concentrated into relatively small areas at the end regions **9**, so as to achieve at these end regions higher temperatures than at the intermediate region where the excitation of the magnetic lens **10** is such that a lesser concentration of the beam is provided and thus its energy is distributed over a larger area, as indicated in FIG. 2. Thus, at the end region where the wire **11** is introduced into the container, it is possible to maintain the desired temperature for the vaporizable material either by way of a sharper concentration of the electron beam in a smaller area through the lens **10**, or by maintaining the beam **7** for a longer period of time at this particular end region of the container, during each cycle of periodic deflection, or even by providing the container with a suitable configuration, as indicated in FIG. 3, or by providing a nonsymmetrical deflection of the electron beam, so that through any one or a combination of these expedients it is possible to compensate for the tendency of the temperature to drop at the region where the new vaporizable material is added to the container. Thus, the distribution of the thickness of the vapor-deposited layer on the work can be enhanced with a given program of deflection of the electron beam in a given period of time also by changing the maximum extent of deflection of the electron beam perpendicularly to the direction of movement of the work **1**. The embodiment of FIG. 4 can be used to achieve uniform angles and areas of contact between the electron beam and the vaporizable material.

The technical and economical effects, and in particular the technical advance which are achieved by the invention, reside in the fact that it becomes possible through the use of relatively simple means to provide vapor-deposition of large workpieces at a high rate of speed and while using the vapor which is formed to a very large extent, the invention being applicable not only to relatively large surface areas which may be stationary but also to continuously moving workpieces. With the process and apparatus of the invention vapor-deposited layers of outstanding homogeneity are achieved.

Furthermore, it is possible to achieve these outstanding results from the programmed deflection of the electron beam, providing at any desired localized area a temperature of the vaporizable material which may be as much as 400° C. higher than the temperature of other parts of the vaporizable material. In this way it is possible to provide vapor-deposited layers throughout the entire width of the work, and for a long period of operation, which are homogeneous and which can be regulated to have any desired properties.

What is claimed is:

1. In a vapor-deposition process in which work which has a pair of opposed side edges is situated over a container for the material which is to be vapor-deposited with the latter container being elongated and extending transversely of the work and having a length from one of its ends to the other of its ends substantially equal to the distance between the opposed side edges of the work, the steps of directing a single electron beam horizontally into a space between the work and the container, magnetically deflecting the electron beam into the container through an open top thereof onto material therein which is to be vaporized for heating the latter material so that it becomes vaporized and deposited in vapor form on a downwardly directed surface of the work, and cyclically moving the magnetically deflected beam along the surface of the material in said container according to a program which maintains the beam in the region of the ends of the container for longer periods of time than in an intermediate region of the container situated between said ends thereof.

2. In a process as recited in claim **1** and wherein the work is in the form of a band moving transversely across the container, the step of cyclically varying the amplitude of deflection of the electron beam in a direction perpendicular to the direction of movement of the work for influencing the distribution of the thickness of the vapor-deposited layer on the work.

3. In a process as recited in claim **1**, the step of cyclically changing the cross sectional area of the electron beam in correlation with the cyclical movement of the magnetically deflected electron beam.

4. In a process as recited in claim **1**, said program of cyclical deflection of said electron beam being nonsymmetrical with respect to a center of the container for the material which is vaporized.

5. In a process as recited in claim **1**, introducing at a predetermined location of the container new material to be rendered molten therein so as to be subsequently vaporized for deposition on the work, and maintaining between the electron beam and the container at said location where the new material is introduced a relationship which compensates for the tendency of the temperature of the material in the container to drop, so that cooling of the material in the container is avoided at said location where new material is introduced.

6. In a process as recited in claim **1** and wherein the magnetic deflection of the electron beam is brought about by way of a plurality of units distributed along the container and each providing its own magnetic field, the step of operating said units in a phase-shifted manner which deflects the beam through substantially the same angle at all parts of the container so that the area of contact between the deflected beam and the material in the container can be maintained substantially constant.

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U.S. Cl. X.R.

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