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PERMANENT MAGNET TRANSVERSE ELECTRON BEAM EVAPORATION SOURCE

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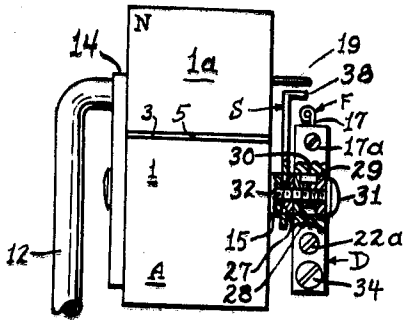


FIG. 4.

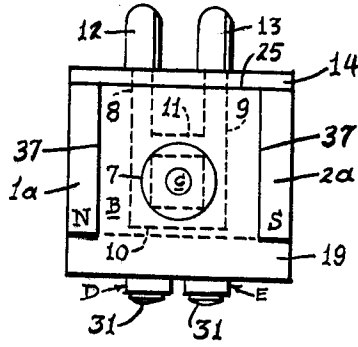


FIG. 2.

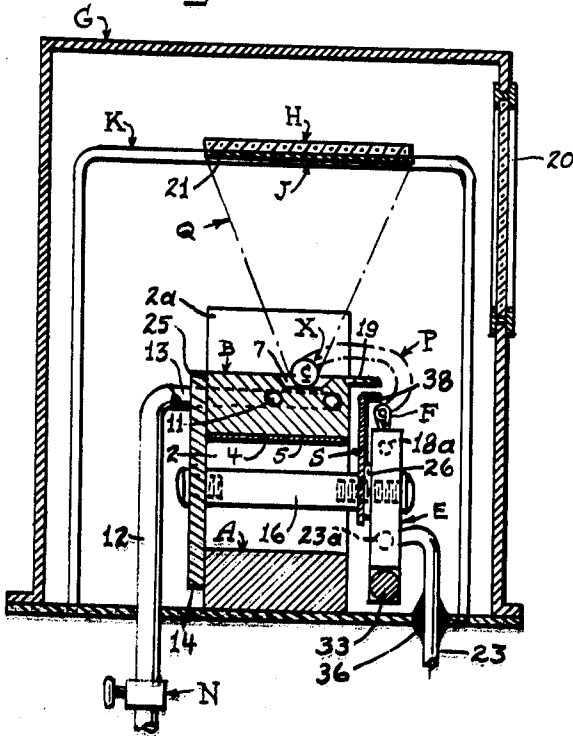
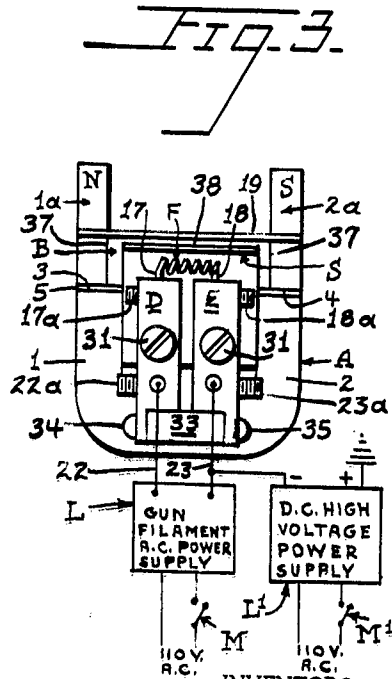


FIG. 1.



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6 Claims. (Cl. 219-121)

The present invention relates to improvements in a permanent magnet transverse electron beam evaporation source and it consists in the combinations, constructions and arrangements hereinafter described and claimed.

In the electron beam evaporation process work, there are essentially three general types of electron guns being used. These are:

(1) Work accelerated type—where the electrons are accelerated by the evaporant.

(2) Self accelerated type—where the electrons are accelerated within the gun and focused from a remote distance in a straight line to the evaporant.

(3) Transverse gun type—a self accelerated gun where the beam is bent with a transverse magnetic field to the evaporant.

The transverse beam gun is generally considered more desirable for evaporation processes because the gun filament is hidden from the vapor and substrate. This feature eliminates possible vapor contamination with the hot filament and also reduces vapor coating onto the gun, which in turn causes electrical shorts and/or arcing.

The primary difference between our device and others now in use is the provision of a permanent magnet to form a magnetic field for controlling the electron beam. By using a permanent magnet, it is possible to decrease the size of the device and make it far more compact. This is important in vacuum use, due to the limited working space of most vacuum systems. This decreased size of the device also lends itself well for special applications such as coating the inside of tubes or other confined areas. Also more than one device may be installed in a vacuum bell or chamber for applying multilayer coatings to articles.

A big disadvantage of using electric magnets in high vacuum systems is that an open electric coil has extreme outgassing characteristics, which increases the pumping time to evacuate the chamber of air and hinders the ultimate pressure attainable. This necessitates either the hermetic sealing of the electric magnet within the vacuum space or the placing of the coils outside of the vacuum space. The economy of using a permanent magnet is also an important factor as both coils and power supplies which must be used with electric magnets are comparatively expensive. Also no heat is generated within the permanent magnet as is the case with electric magnets. The necessary electrical feed-through and power lead needed for a focus coil is also eliminated with the use of our device.

Another feature is that our device works efficiently on either single phase or three phase D.C. high voltage power supplies. Normally an electron beam, being bent by a transverse magnetic field, will not focus satisfactorily when using an unfiltered single phase direct current high voltage power supply, because of voltage ripple. The slower electrons accelerated from the lower voltage will be bent through a shorter trajectory than the faster electrons from the higher voltage. This generally causes the electron beam to have an inefficient focus area over the crucible in which the material to be evaporated is placed. We have found that when the beam trajectory is contained to a short distance the focus spread is minimized. In our device the straight distance between the filament and the crucible is about three-fourths of an inch and there-

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fore the electron beam trajectory is very short. It is therefore possible to hold the focus spread caused from direct current voltage ripple to within an area of about one-fourth of an inch with a voltage range of 4,000 to 5,000 volts. The short beam trajectory attained by a high magnetic flux field from a permanent magnet also minimizes the focus spot movements caused by voltage variations. A variation of 1,000 volts will not move the focus spot out of the crucible in which the material is placed that is to be evaporated.

Other objects and advantages will appear as the specification continues. The novel features of the invention will be set forth in the appended claims.

DRAWING

For a better understanding of our invention, reference should be made to the accompanying drawing, forming part of this specification, in which:

FIGURE 1 is a side elevation of the device with portions being shown in section for purposes of clarity. The device is illustrated as being placed within a vacuum chamber.

FIGURE 2 is a top plan view of the device shown in FIGURE 1 and is shown without the vacuum chamber.

FIGURE 3 is a rear elevation of the device shown in FIGURE 1 and without the vacuum chamber.

FIGURE 4 is a side elevation of the device, a portion being shown in section.

While we have shown only the preferred form of our invention, it should be understood that various changes, or modifications, may be made within the scope of the annexed claims without departing from the spirit thereof.

DETAILED DESCRIPTION

In carrying out our invention we provide a U-shaped permanent magnet indicated generally at A. The sides or legs 1 and 2 of the magnet parallel each other and each has an air gap 3 and 4 respectively that separate the pole pieces 1a and 2a of the legs of the magnet from the main legs 1 and 2 of the magnet. The pole pieces 1a and 2a for the legs 1 and 2 respectively are separated from the legs 1 and 2 by a nonmagnetic shim 5. The shim 5 extends into the air gap 3 and also into the air gap 4. The thickness of the shim may be varied and in this way the magnetic strength of the pole pieces 1a and 2a of the permanent magnet may be varied.

A metal crucible B or hearth made of copper is positioned between the pole pieces 1a and 2a of the permanent magnet. The crucible has a cavity 7 for receiving the material C that is to be evaporated. The crucible or hearth B is water cooled and to this end we provide two parallel water passages 8 and 9 therein and these passages are interconnected by transverse passages 10 and 11. An inlet water pipe 12 communicates with the passage 8 and an outlet water pipe 13 connects with the passage 9. During the operation of the device a continual flow of cold water through the pipe 12 and into the passages 8, 9, 10 and 11, and out through the pipe 13 is maintained. This will prevent the metal forming the crucible or hearth B from melting or evaporating.

The cathode assembly consists of a shield S, filament holders D and E, and filament F. This cathode assembly is mounted on two insulators 15 and 16 which are in turn fastened to a front plate 14. The front plate 14 is soldered or otherwise secured to the front wall 25 of the crucible or hearth B, see FIGURE 1. In fact the shield S is supported by the insulators 15 and 16 and the filament holders D and E are likewise supported by the same insulators. FIGURE 1 shows a metal washer 26 placed between the shield S and the filament holder E so as to contact both. This will give the shield the same voltage potential as the filament holder E.

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FIGURE 4 shows the filament holder D insulated from the shield S. In this figure, the insulator 15 terminates at the shield S. An insulating washer 27 is placed between the shield S and it has a flange that enters an opening in the shield. A pair of insulating washers 28 and 29 are mounted in an opening 30 provided in the filament holder D. A screw 31 has its threaded shank passed through the aligned openings in the insulating washers 27, 28 and 29 and this threaded shank enters a threaded bore 32 in the insulator 15 and secures all of the insulating washers together as a unit. In this way the filament holder D is insulated from the shield S.

In FIGURE 3 we show the lower ends of the two filament holders D and E held in spaced apart relation by a cylindrical insulator 33. The lower ends of the holders have recessed portions to receive the ends of the insulator 33. Screws 34 and 35 secure the ends of the insulator 33 to the holders D and E. The insulators 15 and 16 project beyond the rear of the permanent magnet and space the cathode shield S and filament holders D and E from the magnet. The filament holders D and E support the helical filament F that has its end 17 in electrical connection with the filament holder D and its end 18 in electrical connection with the filament holder E. The filament end 17 is received in a bore (not shown) in the holder D, and a set screw 17a secures the end in place. In like manner the filament end 18 is received in a bore (not shown) in the holder E, and a set screw 18a secures the end in place.

The crucible B has an integral metal lip or flange 19 that projects rearwardly from the back of the crucible or hearth. This metal lip or flange 19 acts as an anode for the device and it overlies the shield S of the cathode assembly. The anode 19 is electrically grounded.

One or more of the devices thus far described is designed to operate within a high vacuum bell G, or other standard vacuum chamber, see FIGURE 1. The bell may be made of a transparent material or it may be made of metal and have a window 20 therein, positioned so that the operator can view the material C which is to be evaporated. The stream of atoms given off by the material C that is being vaporized will travel upwardly in FIGURE 1 when practically all of the air has been withdrawn from within the bell or chamber G. These vapor atoms will strike the undersurface 21 of the substrate H, to be coated and will coat it at J.

In the present instance, the substrate H, to be coated, is illustrated as being a flat member with the flat undersurface 21. Substrates of any desired shape and size up to the limit of the capacity of the vacuum space within the chamber G, may be coated. The substrate that is to receive the coating need not be heated, but generally is in order to aid in the adhesion of the vapor atoms to it. In FIGURE 1, the substrate H, is supported on a frame K, that holds the substrate above the material C that is to be vaporized.

OPERATION

The device with the material to be vaporized and the substrate H are placed in the chamber G and then the air is evacuated by any means, not shown, until a high vacuum within the chamber is established. The electric leads 22 and 23 are connected to the filament holders D and E by set screws 22a and 23a, see FIGURE 3, and also connect with an A.C. filament power supply indicated schematically at L in FIGURE 3. A high voltage D.C. power supply indicated schematically at L1 is electrically connected to the filament F through the lead 23 and the filament holder E. The leads 22 and 23 extend through vacuum tight insulators 36, see FIGURE 1.

A water valve N, for the water inlet pipe 12 is opened and water will flow from the pipe 12, through the passages 8, 9, 10 and 11, to cool the crucible or hearth B, and then will flow out through the outlet pipe 13, see FIGURES 1 and 2. The water-cooled crucible B will keep

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the front plate 14 cooler by conduction because of the direct connection between the two. Also the pole pieces 1a and 2a of the horse shoe magnet A, will be kept cooler because they are soldered or otherwise directly connected to the side walls 37 of the water-cooled crucible B, see FIGURE 3. The front wall of the horse shoe magnet A will contact the front plate 14 and since this plate is cooled by conduction because contacting the water-cooled crucible B, the magnet A will also be cooled by conduction because it contacts the front plate 14.

The D.C. electric high voltage to the filament holders D and E is at a negative potential range between four and five thousand volts although we do not wish to be limited to this particular range. The device is designed to operate at a power of about two thousand watts. Again we do not wish to be confined to any exact wattage. The filament F is heated with the filament power supply to a sufficient temperature to emit electrons. Then the high D.C. voltage L1 is turned on and a stream P of electrons is given off by the filament and is accelerated by the anode.

The electrons emitted from the hot filament A are accelerated by the electrostatic field lying between the anode lip 19 and the cathode lip 38 which extends at right angles to the shield S, and is integral therewith. The stream of electrons P from the filament F, do not strike the anode lip 19, but are accelerated in a straight line from the filament. As the electron stream or beam P, passes through the transverse magnetic flux lines that extend between the pole pieces 1a and 2a and also extend beyond the rear edges of the pole pieces, the electron beam will be bent forwardly or to the left in FIGURE 1. The amount of forward bend of the electron beam depends upon the speed of the electrons in the beam and the number of flux lines it passes. The speed of the electrons is caused by voltage acceleration.

We have found that if a sufficient magnetic flux density is maintained between the permanent magnet pole pieces 1a and 2a at a given operating voltage, the electron beam P will be bent in a very short trajectory and form a small efficient focus spot on the material C in the crucible B. The distance from the gun filament F to the center of the crucible B is about three fourths of an inch. The focus spread at the end of the arcuate electron beam P in travelling so short a distance is held within about a one fourth inch area. This allows sufficient efficiency for the device to be able to operate on a single phase D.C. power supply without the need of using expensive filtering to eliminate voltage ripple. This is quite important because many facilities do not have three phase electric power available. Our device operates at between four and five thousand volts on a single phase power supply with a magnetic flux density of 285 gauss at the crucible center.

The transverse electron beam P will be focused on the material C, in the crucible B and cause this material to evaporate. The evaporated atoms from the material C, will flow upwardly through the vacuum space as indicated at Q and will condense on the undersurface 21 of the substrate H to apply a layer J of the material C onto the substrate H.

In the experiments with our device, the voltage was varied from four to five thousand volts and the focus spot of the transverse electron beam P moved less than one fourth of an inch and remained in the crucible B. It is a simple matter to maintain the desired voltage range at any wattage level. Therefore, by presetting the magnetic field by increasing or decreasing the size of the air gaps 3 and 4 between the pole pieces 1a and 2a and the magnet ends 1 and 2 for a desired voltage level, the focus spot X can be easily controlled and reproduced. In our device, the crucible B has a cavity 7 which is five eighths of an inch in diameter for receiving the material C to be vaporized although we do not wish to be limited to this exact size. The length of time the substrate H

is subjected to the flow of vaporized atoms Q, determines the thickness of the coating J applied.

We have tested our device on various kinds of difficult refractory materials and have found it to be extremely efficient in operation and very reliable. The device has been designed to be used in high vacuum systems and it has definite essential advantages over other existing devices which are now in use.

The electron beam arc P extends through an angle of about 180°. A voltage variation of up to two thousand volts will only move the focus point X about one fourth of an inch by actual experiment. Therefore, a direct current ripple of 50% on a single phase power supply will maintain a high efficiency in the device with voltages ranging up to six thousand volts. This high density field also eliminates focus adjusting when the voltage is maintained within five hundred volts on either side of the designed voltage operation. By keeping the beam trajectory short with the proper voltage and magnetic field density, it is possible to get increased efficiency for a given spot size X. The device can operate on a single phase as well as a three phase D.C. power supply.

A permanent magnet field for controlling the transverse electron beam P has the following advantages over electro-magnetic fields:

(1) There is less outgassing for lower ultimate pressure when using a permanent magnet as against using open electro-magnetic coils.

(2) There is no need for hermetic sealing of electro-magnetic coils within a vacuum compartment or the providing of these coils exteriorly of the compartment. The use of a permanent magnet makes this unnecessary because the permanent magnet may be placed within the vacuum chamber G.

(3) No heat is generated when a permanent magnet is used and heat is generated when electro-magnets are used.

(4) There is no necessity of providing a feed through and a power lead when using a permanent magnet, as is necessary when an electro-magnet is used in a vacuum.

(5) No power supply is needed for a permanent magnet as is necessary when electro-magnets are used.

(6) The device can be made far more compact in size when using a permanent magnet as against using an electro-magnet.

(7) Our device is more economical to manufacture because a permanent magnet is far less expensive than are electro-magnets.

The device design is suitable for use in an ultra high vacuum where the choice of materials and outgassing characteristics are critical. As already stated, there is slight outgassing where a permanent magnet is used. The device is compact in that it is only two and one half inches high. Four devices can be mounted in a twelve inch bell jar. The device is ideal for multi-layer work.

The device will give ultra pure coatings because the filament is hidden from the vapor and substrate. There are no shorting problems. The device can operate indefinitely without any shorting from coating buildup.

The device requires no focus coil and it therefore eliminates the need for a focus coil power supply and lead in wires. The water-cooled crucible will eliminate source contamination. The device is versatile in that it can evaporate any material and its small size lends itself to special applications such as coating the inside of tubes and other confined areas. One of the two pole pieces 1a and 2a, is a north pole and the other is a south pole. These pole pieces receive their magnetism by being held in close proximity to the legs 1 and 2 of the permanent magnet A. The thickness of the shim 5 determines the width of the air gaps 3 and 4 and this determines the magnetic strength of the pole pieces 1a and 2a. The permanent magnet A is removably received in the space provided between the front plate 14 and parts of the

cathode assembly consisting of the shield S, and the filament holders D, and E. The magnetic attraction of the magnet legs 1 and 2 to the pole pieces 1a and 2a, holds the permanent magnet A, in place. The horse shoe magnet A encloses the insulators 15 and 16 and protects them. An electrostatic field is built up between the anode lip 19 and the lip 38 of the cathode shield S and this field will prevent the electron beam P from striking the lip 19.

The materials which are used in the device including the permanent magnet A, can withstand a baking temperature of about 250° C., to outgas for ultra high vacuum environments.

We claim:

1. In combination:

- (a) a crucible having a recess in its top for receiving material to be vaporized and having a front, rear and side walls;
- (b) a pair of spaced apart and parallel pole pieces secured to the side walls of said crucible and projecting above the top thereof;
- (c) a front plate secured to the front wall of said crucible, and depending below the bottom thereof;
- (d) a cathode assembly comprising a pair of insulators secured to said front plate and extending under said crucible and paralleling said pair of pole pieces;
- (e) a cathode shield carried by said insulators and paralleling said front plate and being spaced from the rear wall of said crucible;
- (f) a pair of terminal-supporting holders carried by said insulators and having said cathode shield lying between the holders and said crucible;
- (g) a filament having its ends secured to said holders and connectible to a source of current for causing said filament to give off an electron beam; and
- (h) a permanent horse-shoe magnet having its parallel legs receivable in the space between said front plate and said shield and straddling said insulators, the ends of said legs being magnetically attracted to said pole pieces and causing said pole pieces to be of opposite polarity;
- (i) said crucible having a lip constituting an anode that is spaced above the top of said shield and that electrically cooperates with said shield for preventing the electron beam from striking said anode; said lip preventing the electron beam from making a straight line between the filament and the material in the crucible recess;
- (j) said pole pieces creating lines of magnetic flux of sufficient density for causing said electron beam to form an arc from said filament and focus on the material in the crucible recess.

2. The combination as set forth in claim 1 and in which

- (a) a non-magnetic shim is disposed between the ends of the permanent horse-shoe magnet legs and said pole pieces for altering the density of the magnetic field formed between said pole pieces.

3. In combination:

- (a) a crucible having a recess in its top for receiving material to be vaporized;
- (b) a U-shaped magnet having its pole pieces positioned on diametrically opposed sides of said crucible and projecting above the top thereof for creating a magnetic field over said recess;
- (c) an electron gun positioned adjacent to a side of said crucible intermediate said diametrically opposed sides and below said recess;
- (d) said gun emitting electrons in a path parallel to said side of said crucible and transverse to said magnetic field;
- (e) said magnetic field bending said path of electrons so that it will strike the material in said recess.

4. In combination:

- (a) a crucible having a recess in its top for receiving material to be vaporized;

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- (b) a U-shaped magnet having its pole pieces positioned on diametrically opposed sides of said crucible and projecting above the top thereof for creating a magnetic field over said recess;
 - (c) an electron gun positioned adjacent to a side of said crucible intermediate said diametrically opposed sides and below said recess;
 - (d) said gun emitting electrons in a path parallel to said side of said crucible and transverse to said magnetic field;
 - (e) said magnetic field bending said path of electrons so that it will strike the material in said recess;
 - (f) means for supporting a substrate above the crucible for receiving vapor atoms from the material being evaporated; and
 - (g) a vacuum vessel enclosing said crucible, magnet, filament and substrate supporting means.
5. In combination:
- (a) a crucible having a recess in its top for receiving material to be vaporized;
 - (b) a U-shaped magnet having its pole pieces positioned on diametrically opposed sides of said crucible and projecting above the top thereof for creating a magnetic field over said recess;
 - (c) an electron gun positioned adjacent to a side of said crucible intermediate said diametrically opposed sides and below said recess;
 - (d) said gun emitting electrons in a path parallel to said side of said crucible and transverse to said magnetic field;

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- (e) said magnetic field bending said path of electrons so that it will strike the material in said recess;
 - (f) a shield interposed between said side of said crucible and said gun to prevent any of the evaporate from striking said electron gun;
 - (g) means for supporting a substrate above the crucible for receiving vapor atoms from the material being evaporated; and
 - (h) a vacuum vessel enclosing said crucible, magnet, filament and substrate supporting means.
6. The combination as set forth in claim 3 and in which
- (a) said electron gun is placed close to said side of said crucible and recess for providing a shortened path for the electrons between said gun and the material in said recess which minimizes the spread of the electrons and produces a smaller focus spot in said recess;
 - (b) whereby the focus spot movement is reduced to a minimum when a voltage variation takes place in said electron gun.

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