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ELECTRON BEAM FURNACE AND METHOD FOR HEATING A TARGET THEREIN

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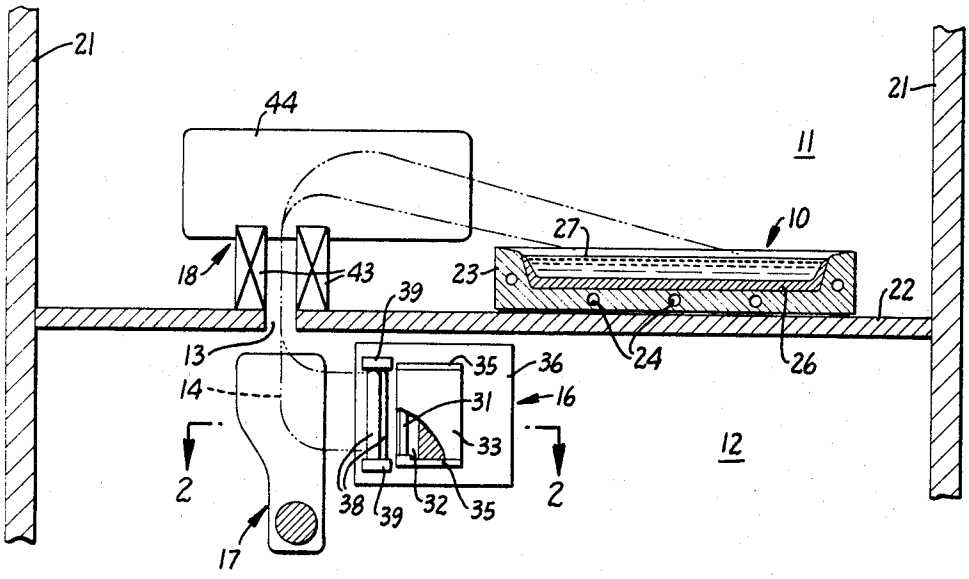


FIG. 1.

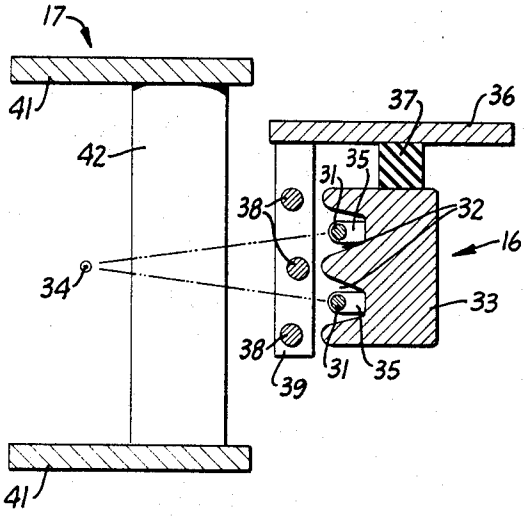


FIG. 2.

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ELECTRON BEAM FURNACE AND METHOD FOR HEATING A TARGET THEREIN

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This invention relates to electron beam furnaces for the vacuum processing of various materials. More particularly, the invention relates to an improved electron beam furnace for heating a target for such purposes as melting, vaporizing, or alloying the target material. The invention also relates to a method for heating such a target in an electron beam furnace by means of a novel arrangement for deflecting the electron beams.

Electron beam furnaces have been used for some time in the vacuum processing of various materials. Such furnaces are utilized, for example, in the melting and casting of metallic ores to obtain relatively pure or alloys. Such furnaces are also used in the melting of materials other than metals, such as ceramics and plastics, and are frequently used to produce vapors of metals and other materials for deposition upon a substrate.

Electron beam furnaces utilize one or more electron guns for producing high energy electron beams. These beams are then directed in some manner to a target for heating the same. Electron beam guns generally comprise an electron source or emitter for emitting electrons and suitable means for generating a magnetic field for accelerating and focusing the electrons into a beam.

The generation of an electron beam and the heating of the target in an electron beam furnace is carried on in a region of high vacuum and, accordingly, the target and the electron beam gun are disposed within a suitable vacuum chamber maintained at a high vacuum. The gun is generally disposed at a convenient location within the vacuum chamber and the electron emitter, which may be an emissive cathode, is energized and heated to emit electrons. The electrons are formed into a beam and accelerated along an initial path by a shaping electrode and a suitable accelerating anode. Magnetic fields are utilized to guide the electron beam onto the surface of the target.

In an electron beam furnace, the heating, melting, or vaporization of many materials produces a large volume of gaseous impurities and vapor particles including ionized and uncharged atoms and molecules in the target area. If the electron gun is positioned in a region of the vacuum chamber where it is exposed to large quantities of the vapor particles and gases, generation of the electron beam may be impaired. For example, wide fluctuation in pressure reduces the efficiency of electron beam production and makes accurate control difficult. Furthermore, if vapor particles strike the emitter of the gun, shorting and erosion of the emitter may occur. In order to avoid this problem, electron beam guns are sometimes located in a position where exposure of the guns to vapor particles and pressure variation is minimized. One of the ways in which this may be done is to locate the electron beam guns in a separate vacuum chamber provided with a separate pumping system which maintains a relatively even and high vacuum in such chamber. The electron beam produced by the gun is directed through an opening

in the wall between the two vacuum chambers to reach the target.

Some vapor particles, including ionized and uncharged atoms and molecules, and some stray electrons will usually be present at the opening between the chambers, and interaction between the electron beam and these items may cause a problem. Negatively charged ions, and stray electrons produced upon ionization of uncharged atoms and molecules by the electron beam, may tend to remain in the electron beam and cause a space charge at the opening which is large enough to hinder direction and focusing of the electron beam through the opening. This problem is further compounded by the desire to minimize the size of the opening and prevent vapor particles from reaching the electron beam gun. Further, during operation of the electron beam furnace, the opening may clog from condensation of vapor and thus become even smaller than its original size.

It is an object of this invention to provide an improved electron beam furnace for heating a target.

Another object of the invention is to provide an improved method for heating a target in an electron beam furnace.

Still another object of the invention is to provide an electron beam furnace wherein the electron beam guns have long operating life and wherein close regulation of power levels and electron beam direction and focus is possible.

A further object is to provide an electron beam furnace and heating method in which the electron gun is positioned in a separate chamber from the target and wherein the tendency for the electron beam to trap stray negatively charged ions and electrons is minimized.

Other objects of the invention and the various advantages thereof will become apparent to those skilled in the art from the following description taken in connection with the accompanying drawing wherein:

FIGURE 1 is a schematic elevational view, with part broken away, of an electron beam furnace constructed in accordance with the invention; and

FIGURE 2 is an enlarged sectional view of the electron beam gun included in the furnace, taken along the line 2—2 of FIGURE 1.

The method of the invention is for heating a target in an electron beam furnace which has a first vacuum chamber **11** containing a target **10**, a second vacuum chamber **12** of higher vacuum and an opening **13** communicating between the first and second vacuum chambers. The method comprises producing an electron beam **14** in the second vacuum chamber at a position offset from the opening. The beam of electrons is deflected and focused in the second vacuum chamber to pass through the opening and into the first vacuum chamber. After passing through the opening, the beam is deflected and focused in the first vacuum chamber to impinge upon the target in a desired manner.

In the electron beam furnace of the invention, a first vacuum chamber **11** contains the target **10** and an opening **13** connects the first vacuum chamber with a second vacuum chamber **12** of higher vacuum. The furnace includes at least one electron beam gun **16** having an emitter **31** positioned in the second vacuum chamber such that it is offset from the opening. A magnetic deflecting and focusing device **17** is positioned in the second vacuum chamber for deflecting and focusing the beam **14** of electrons emanating from the emitter so that it passes through the

opening into the first vacuum chamber. A further magnetic deflecting and fousing device **18** is positioned in the first vacuum chamber and operates to deflect and focus the beam of electrons in a desired manner against the target.

Referring now more particularly to the drawing, the details of the method of the invention will be described. The method of the invention is practised in connection with an electron beam furnace including an enclosed tank having walls **21**, partially shown. The tank is divided into two vacuum chambers **11** and **12** (both partially shown) by a transverse wall **22**. The target **10** to be heated is contained in the first vacuum chamber **11**. The vacuum tank may be a cylinder, or may be rectangular or of other suitable shape. The vacuum chamber **11** is evacuated by a suitable vacuum pump, not shown, to a vacuum which is preferably less than 10^{-2} torr.

The target **10** is positioned in the vacuum chamber **11** and, in the drawings, is shown as a crucible **23** of copper or similar material which is provided with a plurality of coolant passages **24** therein. A coolant such as water may be circulated through the coolant passages to maintain the crucible well below its melting temperature. In the drawings, the melting of a material **27** is illustrated. Such material may be metallic or may be a ceramic or plastic substance. Because the crucible **23** is cooled and because heat is applied to the central portion of the upper surface of the target, a skull **26** of the solid target material will form adjacent the crucible surface. This skull enables a high degree of purity to be obtained in the molten material in the crucible due to the fact that reaction between the molten material and the crucible material is avoided. Of course, the target configuration and material may be other than that shown, and the heating may be for purposes other than melting.

The molten material **27** in the crucible **23** is, as will be subsequently described, heated by electron beams. In such an operation, which is carried out in substantial vacuum, the pressure in the vacuum chamber **11** may vary considerably due to the vaporization of certain impurities in the molten material and due to vaporization of the molten material itself. Because of the continuing nature of the heating operation, the resulting vapor particles, some of which may be ionized, will be always present despite continuous operation of the vacuum pump. The number of vapor particles present will vary depending upon such factors as the constitution of the molten material itself and the power of the electron beam.

In order to minimize the effect of pressure variations and to avoid exposure to large quantities of vapor particles, the electron beam **14** is produced at a location which is less affected by pressure variation and vapor particles. In the invention, the electron beam is produced in a separate vacuum chamber **12**. The vacuum chamber **12** is defined by a portion of the vacuum tank and by the wall **22**. A separate vacuum pumping system, not illustrated, evacuates the vacuum chamber **12** to maintain a high vacuum, preferably less than 10^{-4} torr.

As will be explained subsequently, the electron beam is directed into the vacuum chamber **11** and against the target **10** through the opening **13** in the wall **22**. The opening **13** and the target **10** are maintained in relative positions such that the opening is out of a line of sight from the molten material **27**. Because there is no direct line between the surface of the molten material and the opening, the number of vapor particles passing through the opening and into the vacuum chamber **12** is substantially reduced.

Although the opening **13** is out of the line of sight with the surface of the molten material **27**, the higher pressure in the vacuum chamber **11**, coupled with the fact that there are numerous vapor particles dispersed throughout the chamber, will cause vapor particles to flow through the opening **13** into the vacuum chamber **12**. As mentioned before, the more the vapor particles which reach the electron gun, the greater the detrimental effect on electron beam generation. For example, when vapor particles strike the emitter of an electron gun, shorting or erosion may result in a reduction in the life of the gun.

In order to avoid the vapor particles passing through the opening **13**, the electron beam **14** is produced at a region displaced from alignment with the axis of the opening **13**. The beam indicated by the dash-dot lines in the drawing is shown to be of the ribbon type. However, it is to be understood that other types of electron beam configurations may also be utilized. The ribbon beam produced is deflected in the high vacuum chamber **12** through a generally arcuate path with constant or varying radius. The magnetic fields used for deflection are also designed to focus the beam into a spot of minimum cross sectional area. This helps to pass the maximum number of electrons through the opening. In the illustrated embodiment, the deflection of the beam is about 90 degrees, however, it is to be understood that greater or lesser deflection may also be used in accordance with the invention.

After deflection and focusing, the electron beam **14** is passed through the opening **13** into the vacuum chamber **11**. There, the electron beam is once again deflected and focused onto the surface of the molten material **27**. This deflection may be controlled by an operator observing the process visually through suitable view ports (not illustrated) such as are common in the art.

It has been found that transverse deflection of the electron beam in the manner described reduces interaction of the beam with vapor particles and stray electrons, making it easier to direct and focus the electron beam through the opening **13**. It is believed that this results from the fact that stray electrons are not readily trapped in the electron beam to build up the space charge, but rather tend to more easily pass to other regions of the vacuum chamber **12**. This is of considerable advantage where the vapor particle concentration is high, as around the opening **13**, and thus where the production of stray electrons and negative ions is high. The source of the electron beam may thereby be virtually isolated from the target **10** and yet the desired direction and focus of the electron beam as it strikes the target are easily obtained by transversely deflecting and focusing the beam in the vacuum chamber **11**.

The method of the invention may be more fully understood when considered in connection with the apparatus of the invention, namely, the improved electron beam furnace. The general configuration of the walls of the furnace **21** and the dividing wall **22** have been described above. The electron gun **16** for producing the electron beam may be of any suitable type, however, the particular type of electron gun illustrated has been found especially advantageous in the invention. The electron beam gun **16** comprises two (although only one may be used) elongated emitters or filaments **31** each suitably supported by a pair of conductors **35**. The emitters **31** are disposed in a pair of recesses **32** in an electron beam former **33**. The electron beam former **33**, and particularly the recesses **32** therein, are shaped to focus and direct the beam of electrons produced by the gun and to maximize its density. The emitters **31**, the beam former **33** and the recesses **32** therein are shaped to produce two closely spaced ribbon beams which converge into a single beam at a focal point **34** located in the deflecting magnetic field subsequently described. This convergence allows both of the beams produced by the gun to form a strong composite beam for passing through the aperture **13** in the pressure barrier **22**. If desired, a plurality of electron beam guns may be disposed in the vacuum chamber **12** and deflecting means provided for directing the electron beams through a corresponding plurality of openings arrayed about the target. Such an arrangement provides very high energy transfer to the target. In the drawings, however, only a single gun and associated deflecting means are shown for the purpose of clarity.

Heating current and accelerating potentials are applied

to the various electrodes of the gun **16** through suitable electrical connections, not shown. The electron beam gun **16** is preferably mounted at a slight angle which will compensate for any magnetic deflection of the electrons by the magnetic field created around the emitters **31** by the heating current (preferably direct current). The beam former **33** is mounted to a gun mounting plate **36**, which is at ground potential, by means of an insulated support **37**. The three accelerating electrodes **38** are mounted upon two suitable support and insulator bars **39**, and are maintained at sufficient positive potential to produce the desired electron beam strength. The insulator bars **39** are attached to the mounting plate **36**. As shown in FIGURE 2, the electron beams produced by the emitters **31** pass between the elongated accelerating electrodes **38** to the focal point **34**. The mounting plate **36** supports the gun **16** and is suitably mounted, by means not illustrated, in the vacuum chamber **12**.

The first magnetic deflecting device **17** preferably comprises a pair of pole pieces **41** coupled at either end of a coil **42**. Energization of the coil **42** causes the pole pieces **41** to produce a magnetic field. This magnetic field is shaped by suitably positioning and shaping the pole pieces **41** in order to produce the desired deflection and focusing characteristics. As shown in the drawing, the deflecting device **17** operates to deflect the composite electron beam **14** through about 90° in a generally arcuate path. After being deflected, the electron beam is passing in the direction of the axis of the opening **13**, and is aligned with the opening. Vapor particles passing through the opening, however, do not readily strike the emitter of the electron beam gun **16** because of the position of the gun. Furthermore, the deflecting of the electron beam as described markedly reduces the tendency for space charge buildup at the opening **13**.

It will be noted that the emitters of the electron gun **16** are oriented such that they lie approximately in (actually, on opposite sides of) the plane containing the arcuate path of the electron beam **14** as it is deflected by the magnetic deflecting device **17**. It has been found that this particular orientation of the emitters of the electron gun provides an economical construction, excellent control of the electron beam, and high electron density and power in the beam. In addition, this particular orientation affords certain advantages in deflection of the beam.

The deflecting device **17** is also designed to minimize the cross sectional area of the beam **14** as the beam passes through the opening **13**. Naturally, operating considerations may make it preferable to not reduce the beam to its smallest possible cross section. Thus, the term minimum cross sectional area, as used herein, is meant to refer to the smallest obtainable beam consistent with other operating factors. In order to determine the cross section of the beam as it passes through the opening **13**, metal plates or carbon plates may be placed surrounding the periphery of the opening. Such plates will burn through in the event of excessive divergence or inaccurate deflection of the beam.

The deflecting device **18**, which is located in the vacuum chamber **11**, is shown as being comprised of two separate deflection electromagnets **43** and **44**. The electromagnets **43** and **44** may be of similar construction to that of the deflection device **17**. Such devices are oriented to produce magnetic fields at generally right angles to each other and therefore provide for deflection of the beam in two mutually perpendicular directions. Thus the direction of the beam **14** can be controlled by varying the strength of the two deflecting fields to impinge upon any spot over the entrie surface of the molten material **27**. The electromagnet **43**, as shown in FIGURE 1, is for deflecting the beam in a direction perpendicular with the plane of the paper, whereas the electromagnet **44** is for deflecting the beam in a direction parallel with the plane of the paper. Control of the beam may be exercised by an operator observing the melting operation by providing suitable electrical controls, not illustrated, for the electromagnet power supply.

The invention provides a method and furnace construction wherein the number of vapor particles striking the emitter of the electron gun or guns is minimized. This effects a substantial increase in the gun operating life. Satisfactory control over the electron beam as to its density, strength and direction is facilitated.

Various other embodiments and modifications in addition to those shown and described herein will be apparent to those skilled in the art from the foregoing description and accompanying drawings. Such other embodiments and modifications are intended to fall within the scope of the appended claims.

What is claimed is:

1. A method for heating a target in an electron beam furnace having a first vacuum chamber for containing the target, a second vacuum chamber adjacent said first vacuum chamber, and an opening communicating between the first and second vacuum chambers, said method comprising producing an electron beam in the second vacuum chamber at a position offset from said opening, deflecting and focusing the beam of electrons in the second vacuum chamber so as to cause said beam to pass through the opening and into the first vacuum chamber, and deflecting and focusing the beam of electrons in the first vacuum chamber so as to direct the electron beam against the target.

2. A method in accordance with claim **1** wherein the electron beam is focused in the second vacuum chamber to a reduced cross sectional area prior to passage through the opening.

3. A method in accordance with claim **1** wherein the electron beam produced is of the ribbon type lying generally in a plane and wherein the deflection of the beam in the second chamber causes the beam to follow a generally arcuate path which lies approximately in the plane of the ribbon beam.

4. An electron beam furnace for heating a target, including in combination, a first vacuum chamber for containing the target, a second vacuum chamber adjacent said first vacuum chamber, an electron beam gun including an emitter positioned in said second vacuum chamber, an opening communicating between said first and second vacuum chambers, said emitter being positioned to be offset from said opening, first magnetic deflecting and focusing means positioned in said second vacuum chamber for deflecting and focusing a beam of electrons emanating from said emitter through said opening and into said first vacuum chamber, and second magnetic deflecting means positioned in said first vacuum chamber for deflecting the beam of electrons so as to direct the electron beam against the target.

5. An electron beam furnace in accordance with claim **4** wherein said opening is positioned to be out of a line of sight of the heated surface of the target.

6. An electron beam furnace in accordance with claim **4** wherein said second magnetic deflecting means include means for deflecting the beam of electrons in two mutually perpendicular directions to thereby enable deflection of the beam to any point on the target.

7. An electron beam furnace in accordance with claim **4** wherein said first magnetic deflecting means operate to focus the electron beam to a reduced cross sectional area prior to passage through said opening.

8. An electron beam furnace in accordance with claim **4** wherein said emitter comprises an elongated cathode producing a ribbon-type beam, and wherein said first magnetic deflecting means cause the electron beam to follow a generally arcuate path which is coplanar with said cathode.

9. An electron beam furnace for heating a target, including in combination, a furnace housing defining a vacuum tank, a wall dividing said vacuum tank into first and second vacuum chambers, said first vacuum chamber

being adapted to contain the target, said wall having an opening therein communicating between said first and second vacuum chambers, said opening being positioned to be out of a line of sight of the heated surface of the target, an electron beam gun positioned in said second vacuum chamber, said electron beam gun having a pair of adjacent elongated emitters displaced a substantial distance from the axis of said opening and extending generally parallel therewith, first magnetic deflecting means positioned in said second vacuum chamber for deflecting the beam of electrons emanating from said emitters through a generally arcuate path which is approximately coplanar with said adjacent emitters and through said opening into said first vacuum chamber, and second magnetic deflecting means positioned in said first vacuum chamber for

deflecting the beam of electrons in a desired manner against the target.

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