ELECTRON BEAM GUN SYSTEM

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Related U.S. Application Data

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Int. Cl. ........................................... H01J 37/14
Field of Search .................................... 13/31

References Cited
UNITED STATES PATENTS
3,268,648 8/1966 Dietrich............................ 13/31
3,592,955 7/1971 Hanks............................ 13/31

Primary Examiner—R. N. Envall, Jr.
Attorney, Agent, or Firm—Gregg, Hendricson & Caplan

ABSTRACT
An electron beam gun assembly generates a beam of electrons and directs it transversely into a controllable magnetic lens formed by magnetic fields that are individually variable to tune or control cross sectional beam pattern. The invention is particularly useful in electron beam furnaces.

15 Claims, 7 Drawing Figures
**FIG. 3**

<table>
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<th>AMPERE TURNS</th>
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ELECTRON BEAM GUN SYSTEM

This is a continuation-in-part of my prior copending U.S. Pat. application Ser. No. 393,904 filed Sept. 4, 1973, for "Electron Beam Gun System", now abandoned.

BACKGROUND OF INVENTION

The generation of electron beams and the provision of various types of apparatus for utilization of such beams has long been known in the art. The present invention is particularly directed to the field of electron beam melting of materials and in this field electron beams are commonly generated by electron guns which produce a very high electron density in the space near the emitter, in order to limit the total size of the gun. Focusing of the high velocity electrons emitted from the gun is accomplished by some type of electron lens or lenses which direct the electrons onto the material to be melted. These lenses may be made of shaped electrodes having electrostatic charges impressed thereon to thus appropriately deflect or focus electrons of the beam passing therebetween. In the melting of materials by electron beams the evolution of gases from the heated material produces pressure changes in the evacuated housing about the material and this may cause voltage breakdown between electrostatic lens elements and thus electrostatic lenses are seldom used in this application. The alternative manner of focusing or directing an electron beam is the use of magnetic fields. Such magnetic lenses are almost universally employed in electron beam furnaces and other apparatus used for melting and casting or evaporating of materials.

Magnetic lenses for focusing or directing electron beams may be of two different types, either axial field or transverse filed. Lenses utilizing axial magnetic fields have been very thoroughly researched as, for example, in the field of commercial electron microscopes or electron welders to provide sharply focused electron beams with directional beam movement closely regulated. In axial field lenses the electron paths are substantially parallel to the magnetic field lines; however, serious difficulties arise in attempting to use this type of electron beam focusing in melting and casting or evaporation furnaces. Bombardment of material with electrons to melt the material produces ions and neutral atoms. Because of the line of sight movement of electrons from emitter to target with axial field lenses, the ions generated may travel backwards along this same line of sight to bombard the gun assembly and produce erosion and overheating of the bombardment parts. Additionally, the neutral atoms can condense on electrodes and other parts of the gun so as to change the shape of critical surfaces used in the initial shaping of the electron beam.

In order to overcome ion and condensation problems associated with the use of axial magnetic lenses, it has been found preferable to employ transverse magnetic fields as main focusing lenses in electron furnaces and the like. In this type of lens electrons are directed generally perpendicularly through the magnetic field lines and are consequently constrained to move along a circular, parabolic or elliptoidal curve. The curved electron beam path makes it possible to locate the electron gun emitter in a position remote from the target material and away from any line of sight therebetween. This then removes the electron beam source from the possibility of condensation by neutral atoms and further-more protects the source from ion bombardment inasmuch as transverse magnetic fields deflect ions much less than electrons so that ions do not follow the electron beam path in reverse.

Unfortunately magnetic lenses employing transverse magnetic fields are only incompletely understood so that it has been quite difficult to obtain good electron images therewith. This is not to say that such lenses are unknown. However, the precise control over electron beams therewith has proven quite difficult beyond the general direction or deflection of electron beams thereby. As a matter of interest it is noted that electron magnetic lenses differ from optical lenses in one basic lens characteristic. Optical lenses have a focal length dependent upon the index of refraction which is fixed by the glass forming the lens. On the other hand, electron magnetic lenses have a variable focal length depending upon the value of the index of refraction established by the magnetic field strength. Two magnetic field lenses in series can potentially establish an infinite number of focused and defocused beam cross sections at an infinite number of different magnet coil currents. Thus, although the distance from emitter to target is fixed, an infinite number of changes of focus are possible.

In addition to the above-noted problems of electron beam focusing in furnaces and the like, it is also highly desirable for different applications to provide different cross sectional beam patterns at the target material. Common practice in this respect calls for physical changing of electrodes of the electron gun and associated beam focusing structure. For applications such as the melting in rapid succession of different materials, as by a movable multi-pocket crucible, such physical changes are not practicable.

The present invention provides simple and improved means for changing the shape of an electron beam impingement pattern upon target material, with such means being electrically operable rather than mechanically operable.

SUMMARY OF INVENTION

The present invention provides an electron beam system wherein a generated electron beam is focused and directed as desired upon a target material such as a material to be melted or vaporized. The system hereof incorporates a plurality of electro-magnets and/or permanent magnets for establishing a number of variable transverse field magnetic lenses in the path of the electron beam from source to target. The invention hereof is adapted to provide the transverse magnetic fields in the limited volume through which the electron beam passes, and furthermore provides for variation in separately generated transverse magnetic fields to thus provide the capability of precisely controlling the cross sectional pattern or shape of the electron beam at the target.

The electron beam gun system of the present invention is adapted to be provided as a separate unit which may be employed in conjunction with an electron beam furnace, for example. Rather than forming an electron source, beam forming means and beam focusing means as a part of a furnace, the present invention provides a separate unit generating, directing and focusing an electron beam in a desired pattern at a desired location. The invention is particularly adapted for insertion in the evacuated housing of an electron beam furnace to
provide a tunable or shapable electron beam for the melting and/or evaporation of materials therein.

DESCRIPTION OF FIGURES

The present invention is illustrated as to a single preferred embodiment thereof in the accompanying drawings wherein:

FIG. 1 is a schematic plan view of the electron beam gun system of the present invention in position upon the crucible of an electron beam furnace;

FIG. 2 is a sectional elevational view taken in the plane 2—2 of FIG. 1;

FIG. 3 is a chart relating magnet coil energization to beam pattern in a system in accordance with the present invention;

FIG. 4 is a schematic plan view of an alternative embodiment of the present invention;

FIG. 5 is a central sectional view taken in the plane 5—5 of FIG. 4; and

FIGS. 6 and 7 are central sectional views taken in planes similar to that of FIG. 5 and illustrating additional embodiments of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides a single electron gun system particularly applicable for electron beam furnaces. No attempt is made herein to describe in detail either electron beam furnaces or electron sources, for these are well known in the art. In this respect reference is made to prior issued patents such as, for example, U.S. Pat. No. 3,177,535, wherein there is shown and generally described an electron beam furnace. It will, of course, be appreciated that the present invention is adapted to be operated in an evacuated enclosure for proper beam generation and travel.

Referring now to FIGS. 1 and 2, there is schematically illustrated therein a furnace crucible 11 adapted to contain a material 12 for electron beam bombardment to the end of melting and/or vaporizing same, and including cooling passages 13 for limiting the crucible temperature. The electron beam system 14 of the present invention is shown to be mounted upon or disposed in association with the crucible 11, preferably in detachable association therewith. Details of connection or mounting may obviously vary in accordance with the particular furnace configuration and crucible structure and thus no details thereof are included herein.

The present system includes a block 16 of copper or the like adapted to be disposed on top of the crucible 11 and having a funnel shaped opening 17 communicating with the open top of the crucible. The block is also provided with an opening 18 there through outwardly of the funnel shaped opening 17 and extending vertically through the block for passage of an electron beam, as described below. The opening 18 also preferably extends longitudinally of the block at the top thereof to the funnel shaped opening 17 to provide a configuration such as illustrated in FIG. 2.

There is provided as a portion of the present invention an electron beam source or gun 21 which may in itself be relatively conventional in including an emitter, focusing elements and associated structure, directing therefrom a beam of electrons 22. The electron beam 22 is generated and accelerated from the gun 21 as a high density cloud of high velocity electrons and the present invention provides for focusing of such beam into a desired shape and directing such beam along a desired path into impingement with the upper surface of the material to be operated upon. In accordance with the present invention, the electron gun 21 is disposed at one side of the crucible 11 and directs the electron beam from the gun generally away from the crucible.

Controlled focusing of the beam is herein accomplished by the establishment of controllable or adjustable magnet lenses by magnetic fields having lines of force transverse of the path of electrons passing therethrough. In the embodiment of FIGS. 1 and 2 the magnetic fields are established by magnets 31, 32 and 33 with an additional magnet 34 being optionally provided for reasons set forth below. Each of the magnets may have pole pieces provided as elongated generally parallel ferromagnetic plates 36 and 37, or the pole pieces may be separated as described below. The magnet 31 comprises a central ferromagnetic element or core 41 having a magnet coil 42 wound thereabout for generating a magnetic flux upon coil energization to extend between the pole pieces. The magnet 32 includes a ferromagnetic core structure 43 extending transversely between the pole pieces 36 and 37 and a magnet coil 44 wound about this core to establish a magnetic flux extending between the pole pieces. The magnet 32 is preferably limited in its extent above the edge of the crucible, as illustrated in FIG. 2, in order to prevent any possible interference with the electron beam travel as by extension into the beam path. The electron gun 21 is disposed between the magnets 31 and 32 below the opening 18 in the block 16 and magnets 32 and 33 are disposed on opposite sides of the crucible 11, all in the block 16, as illustrated.

The magnet 33 is provided on the opposite side of the crucible 11 from the electron gun 21 and magnets 31 and 32 and includes a ferromagnetic core 46 and magnet coil 47 disposed thereabout, as illustrated. The magnet 34 extends between the pole pieces 36 and 37 and may comprise a permanent magnet or an electromagnet including core 48 and coil 49, for reasons described below.

Appropriate water cooling conduits 51 are provided in connection with the block 16 in order to minimize overheating of such structures.

Each of the magnetic coils 42, 44, 47 (and 49 when provided) is separately connected to control means which provides for controllable energization of each of the magnet coils in order to separately adjust the magnetic field strength of each of the electromagnets. When desired the controls may be interconnected to provide single-knob control of the change of beam pattern from one desired pattern to another.

The structure of the present invention described above includes common magnet pole pieces for each of the electromagnets; however, it has been found that for some magnetic geometries, a better separation between separate lenses of the present invention may be obtained by separating the pole pieces. Thus in FIG. 2 there is illustrated pole pieces 36a and 37a of electromagnet 31. Similarly, electromagnet 32 is provided with separate pole pieces 36b and 37b, while common pole pieces 36c and 37c are provided for electromagnets 33 and 34. The separate pole pieces of each of the electromagnets are shown in parallel alignment, as illustrated in FIG. 1, and the separation between adjacent pole pieces is preferably made about one-tenth to
one-half of the length of the pole gap for an individual magnet. This then provides a somewhat better separation of the individual lenses formed by the electromagnets. The inner facing surfaces may be shaped to aid in producing the necessary magnetic gradients for correct lens action.

Referring now to the actual focusing of the electron beam, it is noted that the electromagnets 31, 32 and 33 generate electron lenses 61 and 62 in the volumes generally denominated by these numbers in FIG. 2. The strength of these lenses and the actual configurations thereof are readily adjustable by the control 63 whereby the current through individual magnet coils may be set to establish the desired lens configuration and strength. By the provision of these two transverse magnetic field lenses wherein each of the lenses may be varied, the present invention provides the capability of precisely focusing the electron beam 22 onto the upper surface of the material 12 and at the same time provides the control necessary to operate the beam or continually adjusting the cross sectional beam pattern. In this respect reference is made to FIG. 3 setting forth relationships between magnet coil energization and beam pattern and dimensions for one particular electron gun system formed in accordance with the present invention. The embodiment of the invention from which the data of FIG. 3 was taken provided a pole piece separation of the magnets of about 3½ with the coil spacing about as illustrated in FIGS. 1 and 2. The system was operated at a beam voltage of 10 KV and 100 ma current. It will be seen from FIG. 3 that the size and shape of the electron beam at the target material may be readily controlled and varied by adjusting the current to the magnet coils. This then provides a material advancement in the art, as further discussed below.

It has been noted about that the magnet 34 may be optionally provided and in this respect it is further noted that such magnet may be utilized to sweep the beam over the surface of the material 12. For some applications it is beneficial to move the area of beam impingement on the target material, possibly in a regular manner, and by applying a varying energization to the coil 49 this may be readily accomplished with the present invention. In situations wherein no sweeping of the beam is necessary the magnet 34 may be provided as a permanent magnet employed to provide a general bias to the main magnetic field. In this way the coil current required in the magnet 33 may be minimized so as to reduce I^2R losses in the system.

Sweeping of the beam may also be accomplished by dividing the magnet coil 44 into a plurality of coils such as 44a and 44b which may be separately and controllably energized to operate on the beam over substantially the entire path thereof by a magnetic field varying in field strength laterally.

The actual configuration of the magnetic fields generated by the system of the present invention may, of course, be varied to tune particular lens configurations and thus achieve different effects upon the electron beam passing therethrough. The electron beam emitted by the source 21 is initially divergent and is herein focused into a pattern of adjustable shape and size in the target area. This focusing is highly advantageous when the beam is employed in the melting and casting or evaporation of materials. Different materials require different amounts of energy density to obtain the most beneficial results in these applications. For example, some material such as quartz and chromium sublime in vacuum and do not have a truly molten area of any sizable extent. Consequently these materials cannot seek a gravity-induced level surface in the fluid state and instead evaporate from the surface in the area that happens to be heated hotter by a locally more intense beam. This results in the production of holes or surface depressions which causes an undesirable molecular beaming of vapor atoms and seriously distorts evaporation patterns. Thus for materials of this type a more uniform evaporation pattern can be achieved by changing the shape of the beam impact area, and when this is combined with a regular movement of the beam over the surface of the material, a superior evaporation effect is achieved. High rate evaporation of materials (i.e., above 12,000 A angstroms per minute at 10 above the source) provides a density of the cloud of vapor atoms at the source surface that sometimes is 4-5,000 times greater than the beam or continuous area. Such a high density of atoms intercepts the incoming electrons and causes them to spend their kinetic energy in heating up the vapor atoms rather than in increasing the heat of the surface atoms in the pool. As an example, a small tight hot electron beam of 5 KW energy impinging on aluminum produced an evaporation rate of 13,000 A angstroms per minute at a 10 height above the source. By defocusing the beam and tuning it to a maximum an output of 19,000 A angstroms was achieved. The beam impact size was about 75 percent larger in area. At 10 KW a beam tuned for maximum evaporation rate is slightly more than double the size of the most tightly focused beam and gives a rate more than double the rate of a tight, hot, beam spot. The present invention is particularly adapted for electron beam control or tuning to achieve optimized vaporization identified above.

A further example of the advantages of a changeable beam pattern in electron beam evaporation systems is found in the type of furnace employing a multi-pocket crucible that may be employed to provide multiple layers of two or more different materials successively evaporated from different pockets. One example of the foregoing is found in the production of integrated circuit silicon chips wherein appropriate masks are employed for depositing such diverse evaporants as Al, SiO2, Ni, Cr, Cu, Au, Al2O3, and others. For this application a multi-pocket crucible is employed to move the succession of evaporants under the electron beam impact area. The evaporation of such diverse material is greatly benefited by using a small, very hot spot of electron beam for materials that melt at high temperatures, such as tungsten or molybdenum, or form large liquid pools and a wider, more diffuse beam for materials that sublime or otherwise act adversely under localized high heat flux. Thus the present invention is particularly advantageous for applications wherein there are successive evaporations of different materials that have widely different melting and evaporating characteristics.

It is further noted that the present invention provides a magnet structure establishing magnetic fields that are generally confined to the areas or volumes through which electrons move. Thus magnetic fields are established in the area of the electron beam path between gun and crucible and in the area at the back of the crucible and beyond where stronger magnetic fields are needed to make the secondary electrons generated by
the impact of the primary electrons on the evaporant surface curve downwardly for non-destructive impingement upon water-cooled hearth structure near the crucible. The capture of secondary electrons in this manner prevents their escape from the vapor source and consequently unwanted heating of adjacent structures in the vacuum chamber.

It will be appreciated that the present invention provides for location of the electron gun 21 in a protected position so that it is not bombarded by positively charged ions nor is it in position to have vapor molecules deposited thereon. The magnetic system of the present invention operates upon the electron beam 22 to curve this beam through an angle of the order of 180°-270°. Additionally it is noted that the electromagnet 32 is disposed in position to have the electron beam curve thereabout so that the field of this magnet influences substantially the entire traverse of the beam. In accordance with the present invention, magnet 32 may be energized to apply lateral forces to the electron beam for sweeping the beam back and forth over the top of the crucible as, for example, by splitting the magnet coil 44 into a number of parts that are separately energized. This then provides the capability of operating upon the beam over substantially its entire traverse with magnetic fields for beam sweeping. This is highly advantageous in that the substantial beam path in the sweeping field or fields allows the use of lower strength sweeping fields with a consequent saving in magnet coil current and reduction in heating.

The present invention may also be embodied in much simpler form than described above. It is possible to achieve a desired electron beam focusing with an electron lens formed by magnetic fields of force transverse to an electron beam path with only two variably energized magnets. While certain advantages of the present invention may be sacrificed thereby, it is yet possible to achieve a major advancement of the present invention with only two variable magnetic fields establishing a single controllable or adjustable magnet lens as noted above. In this respect reference is made to FIGS. 4 and 5 wherein the coil is shown the above-described magnets 31 and 32 spaced from a furnace crucible 11 and having an electron beam source 21 directing a beam of electrons 22 into a magnetic lens formed by these magnets 31 and 32. In this embodiment of the present invention the magnets 33 and 34 of the embodiment of FIGS. 1 and 2 are eliminated. The magnet 31 includes a magnet core 41 surrounded by a copper coil 42 and disposed, for example, in a block of copper 71, with magnet pole pieces 72 and 73 extending from the ends of the core and coil toward the furnace 11. The magnet 32 is comprised of a magnet core 43 and a magnet coil 44 thereabout disposed at least in part within a copper structure or the like intermediate the magnet 31 and crucible 11. The electron beam source 21 is again preferably located beneath or at least in shielded relationship to the crucible 11 and between the magnets 31 and 32. The magnet 32 has pole pieces 76 and 77 extending from the ends of the magnet core and coil in parallelism toward and, in fact, beyond the crucible 11 or at least the opening therein. The pole pieces of the magnets 31 and 32 are preferably separated, although it is possible for these pole pieces to be contiguous, as described above.

There is established by the variable magnetic fields of the magnets 31 and 32 a magnetic lens which is adjustable or controllable by controlling the current through these magnets 31 and 32 so as to establish a desired electron beam cross sectional configuration impinging upon a desired focus area 78 of material 12 in the crucible 11. Electron beam focusing, in accordance with the present invention, is controlled by varying the currents to the coils of the magnets 31 and 32, as by a control 79, so as to establish a desired magnet lens in the path of the electron beam 22. It will, of course be appreciated that it is possible to appropriately shim or configure the pole pieces 76 and 77 so as to achieve desired field configurations and gradients in the vicinity of and beyond the crucible 11. It will also be appreciated that the controllable or adjustable magnets 31 and 32 establish a sufficient field strength so that the electron beam 22 does not pass out of the major influence thereof above the pole pieces of these magnets to thereby ensure appropriate curvature of the electron beam path so that such beam is indeed focused upon the surface of the material 12 in the crucible 11. The electron beam is at all times traversing a path subjected to the influence of the lines of force of the magnets of this invention, for it is only within a transverse magnetic field that the electron beam will continue to be influenced and consequently curved in accordance with the illustration of FIG. 4. No attempt is made in the illustrations of this invention to precisely delineate the path of the electrons but instead such path is only schematically illustrated as being influenced by and furthermore controllably focused by the magnetic fields established in accordance with this invention.

It was stated above herein that the present invention, as described in connection with the embodiment of FIGS. 1 and 2 hereof, may be simplified by the elimination of one or more magnets. In addition to the further embodiment of FIGS. 4 and 5, there are illustrated in FIGS. 6 and 7 additional simplifications of the present invention which are capable of accomplishing the primary objects of the present invention. Referring to FIG. 6 there will be seen to be provided in addition to the furnace crucible 11, the above-described magnet 31 disposed to the right of the electron beam source 21 of FIG. 6, and the electromagnet 33. The adjustable or controllable magnets 31 and 33 are disposed on opposite sides of the crucible and electron beam source combination. The electromagnet 31, including the core 41 and coil 42 thereabout, extends between the above-described pole pieces 72 and 73, while the electromagnet 33, having core 46 and surrounding coil 47, extends between pole pieces 81 which are preferably aligned with the pole pieces of magnet 31 on opposite sides of the crucible 11 and electron beam source 21. In this embodiment of the present invention the electron beam 22 traverses a volume through which extends the adjustable or controllable transverse magnetic fields established by the magnets 31 and 33. The electron beam 22 passes through a variable or controllable magnetic lens and is consequently precisely adjustable as to focus thereof upon the surface of the material 12 in the crucible 11.

It will be appreciated that various structural modifications may be required for the embodiment of FIG. 6 and it is also noted that the pole pieces of the electromagnets 31 and 32 may possibly be contiguous or may be separated by a pole gap 82, as illustrated in FIG. 6. The strength of the magnetic lens formed between the magnets 31 and 33 is increased by the provision of a
pole gap 82 and the dimensions of this pole gap are substantially the same as described above in connection with the embodiment of FIGS. 1 and 2.

In FIG. 7 there is illustrated yet another embodiment of the present invention incorporating but two electromagnets 32 and 33. In this embodiment of the present invention an electron beam 22 emitted from the source 21 is influenced by the transverse electromagnetic field of the magnet 32 so as to traverse the path illustrated and the magnets 32 and 33 together establish a variable magnet lens between these magnets wherein the electron beam 22 is controllably focused into a desired configuration upon the surface of the material 12 in the crucible 11. The magnet 33 is illustrated as having magnet pole pieces provided as parallel plates 81 extending from the opposite ends of the magnet over the crucible 11. The variable magnet 32 is illustrated as having parallel pole pieces 86 extending across the ends of the magnet core and extending a sufficient distance to the right in FIG. 7 to maintain the electron beam 22 within the transverse magnetic field established between these pole pieces 86 in such volume. Again it will be noted that it is possible to shim or preferentially contour the faces of the pole pieces 86 so that the electron beam in passing therebetween will be appropriately influenced by the magnetic field established by the magnet 32. Here again the pole pieces 81 and 82 are illustrated to be separated by a gap 87 for maximizing the possible effects of the magnet lens established by the transverse magnetic fields between the magnets 32 and 33, respectively; however, it is at least possible to form the magnet pole pieces 86 and 81 contiguously. Under all of the foregoing circumstances there is established by the present invention a magnetic lens formed of magnetic lines of force transverse to the path or median plane of traverse of the electron beam 22 between the source 21 and material 12 in the crucible 11. This controllable or adjustable magnetic lens formed of transverse lines of force provides the present invention with the capability of varying the focus of electrons upon the upper surface of the material 12 in the crucible 11. The advantages to be gained by such control have been set forth above and thus are not reiterated herein.

The embodiments of the present invention illustrated in FIGS. 4 to 7 incorporate but two controllable electromagnets producing lines of force transverse to the median plane of electron beam traverse to establish a controllable or adjustable magnet lens for varying and precisely adjusting the focus of the electron beam 22 upon the upper surface 12 of the material in the crucible 11. In the embodiment of FIG. 7, as in the embodiment of FIG. 4 above, it is possible to provide appropriate pole piece contours or magnet shims to achieve a desirable magnet field gradient between the outer ends of the magnetic pole pieces 86 so that the electron beam 22 does in fact follow a path as is generally illustrated by the dashed lines in FIG. 7.

The alternative embodiments of the present invention, illustrated in FIGS. 4 to 7 above, are capable of accomplishing many of the objects of the present invention; however, it will be appreciated that these embodiments may not provide the total degree of electron beam control as is provided by the embodiment of FIGS. 1 and 2. Consequently it will be appreciated that the preferred embodiment of the present invention is illustrated in FIGS. 1 and 2 hereof; however, the embodiments of FIGS. 4 to 7 fall within the general purview of the present invention and are, in fact, applicable or even preferable for particular applications of the present invention. It will be apparent to those skilled in the art that the embodiments of FIGS. 4 to 7 are less complex require less magnet structures so as to commend these embodiments to simplified applications of the invention and do result in savings of cost of construction and operation. In all cases it is contemplated that the present invention shall be capable of application to existing electron beam furnace structures.

The provision of a unitized gun and magnetic system is also advantageous in that the invention can thus be used on top of nearly any crucible or component of a size roughly equivalent to the crucible opening of the bottom of the second lens area. Prior art electron beam evaporating systems have employed magnet structures built into the crucible component in a non-removable manner, i.e., the magnet structure forms an integral part of the overall furnace. In the present invention this is not the case and thus the system of the present invention is removable and is applicable for use in different furnaces and for different applications. The versatility of the system of this invention commends it to widespread use under varying conditions and with differing materials.

Although the present invention has been described above in terms of particular preferred embodiments thereof, it will be appreciated that variations may be made within the spirit and scope of the present invention. It is consequently not intended to limit the present invention by the precise details of the illustrations or terms of description.

What is claimed is:

1. An electron beam gun system for an electron beam furnace comprising
   first and second electromagnets disposed in substantially parallel spaced relation,
   an electron gun disposed between and below said first and second electromagnets,
   a third electromagnet disposed in substantially parallel spaced relation to said second electromagnet and adapted to have a crucible or the like disposed therebetween for electron bombardment of material contained therein, and
   controllable energization means connected to each of said electromagnets for establishing a first variable magnetic lens between said first and second electromagnets and a second variable magnetic lens between said second and third electromagnets whereby electrons emitted from said electron gun are controllably focused into a beam of variable cross section at said crucible.

2. The system of claim 1 further defined by a fourth electromagnet disposed adjacent said third electromagnet and means controllably energizing said fourth electromagnet for sweeping the beam over material disposed in said crucible.

3. The system of claim 1 further defined by said electromagnets having common pole pieces.

4. The system of claim 1 further defined by each of said electromagnets having separate pole pieces with the separation between pole pieces of adjacent magnets being of the order of one-fifth the length of the electromagnets.

5. The system of claim 1 further defined by a fourth permanent magnet disposed adjacent said third electro-
magnet and providing a portion of the magnet field for said second magnetic lens.

6. The system of claim 1 further defined by said second electromagnet having a coil divided into at least two parts and connected for separate energization for providing a laterally varying magnetic field to laterally sweep the electron beam.

7. The system of claim 1 further defined by said electromagnets and gun being mounted together to provide a unitary system adapted for use with different crucibles.

8. The system of claim 1 further defined by said electron gun emitting high velocity electrons in a direction away from said second and third electromagnets and said magnetic lenses redirecting said electrons in a beam along a curved path over said second electromagnet and downwardly between said second and third electromagnets.

9. The system of claim 1 further defined by said first and third electromagnets being substantially disposed in a common plane and said second electromagnet being disposed slightly below said plane for ready passage of said electron beam over said second electromagnet.

10. An electron gun system for an electron beam furnace comprising
    first and second magnets disposed in substantially parallel spaced relation,
    an electron gun disposed between and below said first and second magnets,
    means varying the field strength of said first and second magnets for directing an electron beam emitted from said electron gun along a controllable path, and
    a third magnet disposed in substantially parallel spaced relation to said second magnet on the opposite side thereof from said first magnet and adapted to have a crucible or the like disposed between said second and third magnets for the direction of said electron beam therein.

11. The system of claim 10 further defined by said second magnet comprising a multiple coil electromagnet and means controllably energizing each of the coils thereof for establishing a laterally variable magnetic field over substantially the entire electron beam path to sweep the beam over said crucible.

12. An improved electron beam focusing system comprising
    first and second parallel spaced apart electromagnets having parallel pole pieces,
    an electron source directing electrons into the magnetic field of at least one of said electromagnets transversely of the lines of force thereof for establishing a curved electron beam path, and
    variable power supply means connected to differentially energize said electromagnets to establish a controllable non-uniform transverse field magnetic lens for controlling the focus of said beam at a target area.

13. The system of claim 12 further defined by said electron source being disposed intermediate said first and second electromagnets, and
    the pole pieces of said second electromagnet extending therefrom away from said first electromagnet for disposition upon opposite sides of an electron beam target area.

14. The system of claim 13 further defined by said pair of electromagnets being spaced apart for disposition upon opposite sides of a furnace crucible and said electron source being disposed between said electromagnets for directing electrons into the volume between the magnets.

15. The system of claim 13 further defined by said electromagnets being spaced apart for disposition upon opposite sides of a furnace crucible, said electron source being disposed on the opposite side of the first magnet from the second magnet and the pole pieces of the first magnet extending from the first magnet in a direction away from the second magnet for maintaining a magnetic field therebetween curving the electron beam path between said magnets.

* * * * *