219-121

Nov. 19, 1968 W. D. FIGGINS 3,412,196

ELECTRON BEAM VACUUM MELTING FURNACE

Filed July 13, 1966

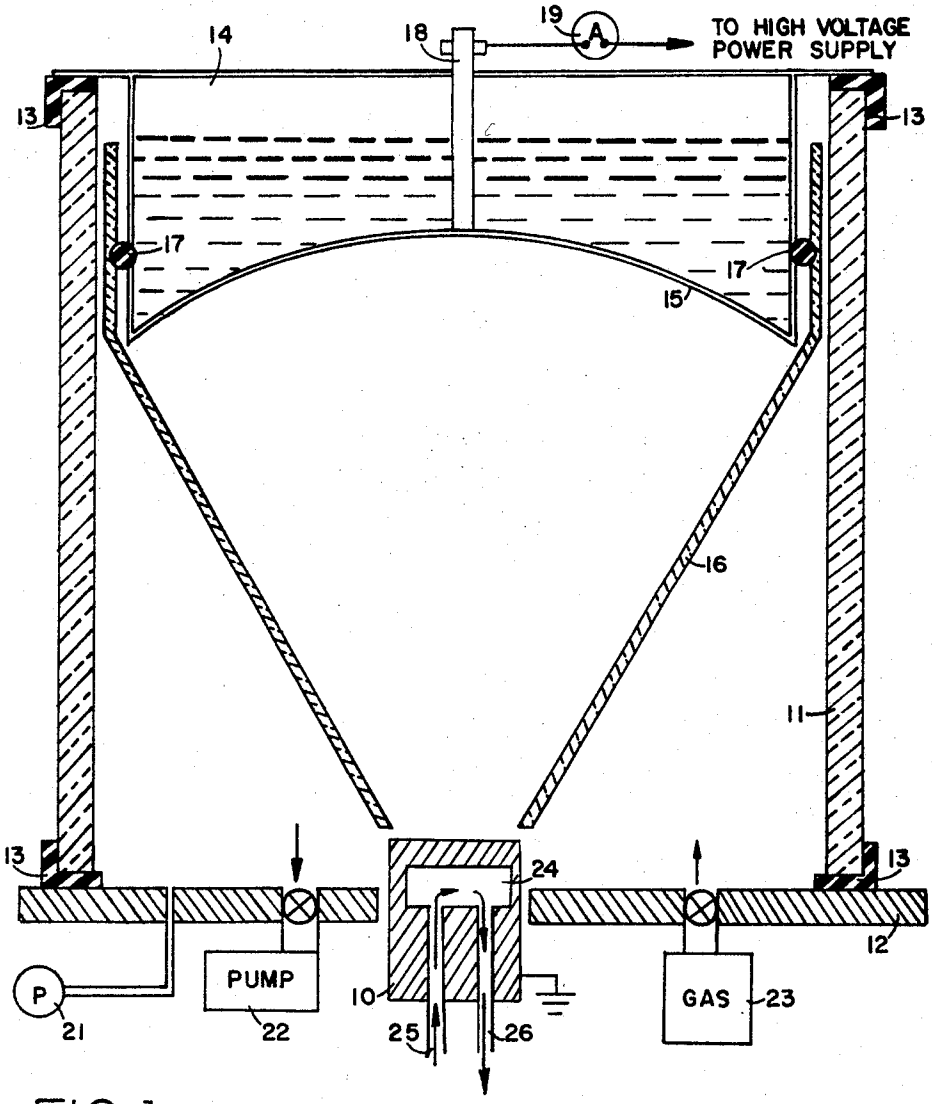


FIG. 1.

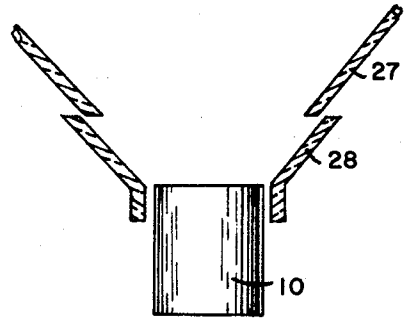


FIG. 2.

INVENTOR.
WILLIAM D. FIGGINS
BY Richard D. Seligman
ATTORNEY

United States Patent Office 3,412,196 Patented Nov. 19, 1968

3,412,196

ELECTRON BEAM VACUUM MELTING FURNACE

William D. Figgins, Nashua, N.H., assignor to Sanders Associates, Inc., Nashua, N.H., a corporation of Delaware

Filed July 13, 1966, Ser. No. 564,957
19 Claims. (Cl. 13—31)

ABSTRACT OF THE DISCLOSURE

An electron-ion beam device, and more particularly a furnace operating under a condition of partial vacuum, for heating, melting, welding, or evaporating materials, employing electron beam techniques. A vacuum chamber is filled to a low pressure with a gas after prior evacuation to remove undesirable vapors and gases. A high voltage is applied to an electrode to produce a plasma between a concave cathode surface and an anode, which anode is used as a crucible. Electrons are extracted from the plasma and mechanically focused by means of a converging focusing cone to produce an intensified electron stream at the crucible.

This invention relates to an electron-ion beam device, and more particularly to apparatus for heating, melting, welding, or evaporating materials, employing electron beam techniques.

It is well known in the art to use high density electron beams to heat, melt, weld, evaporate, etc. materials. The prior art discloses methods of accomplishing the above-outlined objectives by causing a cathode to emit electrons in a controlled atmosphere, which electrons are then directed toward the material so as to heat the material. Included in these devices are means for directing and increasing the density of the electron stream, for example, by employing magnetic, electro-mechanical or electrostatic focusing. Although these known focusing methods have been successful, they are encumbered, in that they are relatively complex and costly, usually requiring additional power sources for the focusing apparatus.

Accordingly, it is an object of this invention to provide an improved electron beam device.

Another object of this invention is to provide an improved electron beam vacuum melting furnace.

An additional object of this invention is to provide an electron beam vacuum melting furnace employing mechanical focusing.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a sketch illustrating a first embodiment of an electron beam vacuum melting furnace employing mechanical focusing; and

FIG. 2 is a sketch of a partial view of the embodiment of FIG. 1, illustrating a modification of the method for providing the mechanical focusing.

Briefly, the embodiment illustrated provides an improved method of melting materials having high-temperature melting points in an inert gas atmosphere, and comprises a cathode and anode arranged within a controlled atmosphere, the anode being a crucible in which the substance to be melted is placed. The cathode-to-anode potential is made high, ionizing the inert gas which produces a plasma and causes an electron beam to be extracted from the plasma. The electrons from the plasma go to the anode and the positive ions go to the cathode. The electron flow is mechanically focused i.e., the electron flow is electron-optically focused by use of a

mechanical member, to produce a high density electron stream at the crucible. The focusing arrangement in one embodiment includes a frusto-conical member made of a heat resistant glass such as that sold under the trademark "Pyrex", quartz, or a refractory material having its focal point at the sample to be melted.

Referring to FIG. 1, there is therein illustrated an embodiment of the invention. The sample to be melted is placed within a crucible **10**, which is maintained at a high electrical potential relative to a cathode. The cathode potential could be a large negative value with the anode being at electrical ground potential. Crucible **10** is located within an outer chamber **11**. Crucible **10** in one embodiment, is constructed of copper or a suitable high conduction material, and outer chamber **11** in one embodiment, is constructed of Pyrex.

Chamber **11** is arranged upon a base plate **12** employing a gasket **13** to provide a good vacuum seal. Arranged in the upper portion of chamber **11** is a cathode member **14** having, in the preferred embodiment, a concave surface **15**. It is obvious that the concave surface could be replaced by a straight cathode surface or one of various other shapes. The concave cathode surface is preferred because it offers some degree of focusing in itself. The concave cathode surface has the characteristics of an electron-optical lens. The focal point of the concave cathode could be arranged at the sample to be melted. The degree of focusing of the concave cathode could be increased by increasing the cathode-to-anode potential and/or decreasing the pressure within chamber **11**. Cathode structure **14** in the embodiment illustrated preferably has a hollow interior, so that it can be filled with water or other substance for cooling purposes. The cathode-to-outer chamber bonding is also accomplished with a vacuum gasket **13**. A beam-focusing cone **16**, in the preferred embodiment having a frusto-conical configuration, is disposed about cathode member **14** using an O-ring **17**. Although in the embodiments illustrated, the mechanical focusing device is shown as having a conical configuration, this is illustrative only; and other various shapes could be employed to provide a converging path for the electron stream. The focusing cone is preferably arranged to encompass the cathode surface, as shown in FIG. 1, in order that all the electrons extracted from the plasma enter the cone for focusing onto the anode. Cone **16** is arranged so that the apex thereof is at or near crucible **10**. The beam-focusing cone **16** can be made of Pyrex, fused silica, or a refractory material having suitable insulating and other characteristics. If focusing cone **16** is made of Pyrex, fused silica or other quartz material, all of which can be made transparent, a desirable feature occurs, in that an experimenter can view the plasma within cone **16**, as well as the sample being melted. Cone **16** could also be made of a metal, but this would require adequate shielding, as well as presenting other problems.

Connected to cathode **14** is an electrode **18** which is coupled to a high voltage power supply (not shown) by way of an ammeter **19**. Pressure is monitored within the interior of outer chamber **11** by employing a thermistor or thermal couple contained within a metering device **21**. The use of a thermistor or thermal couple is illustrative only, and sundry other devices known in the art could be used to monitor the pressure. A vacuum pump **22** is employed to remove the atmosphere from within chamber **11**. A gas source **23**, which in this embodiment contains argon gas, has an inlet to chamber **11** for supplying gas thereto. The interior of crucible **10** has a chamber **24** therein such that water or other liquid coolant can be passed therethrough via pipes **25** and **26**.

The system above described provides a means for melting refractory and other high temperature materials in an inert atmosphere of argon gas.

The sample to be melted is placed within the water-cooled crucible **10**. The interior of chamber **11** is pumped out by pump **22** such that a substantial vacuum remains therein. The chamber pressure is usually reduced to less than one micron. Argon gas from gas supply **23** is then admitted into the chamber, and the pressure therein is adjusted to a level which is dependent upon the material to be melted. A high voltage is applied to electrode **18**, whereby the argon becomes ionized producing an argon plasma; and electrons are extracted from the argon plasma and go to the anode **10** (crucible). The argon gas is supplied to maintain a relatively constant pressure, and provides purity of the atmosphere as well as a breakdown path for the electron stream. Pump **22** is maintained in constant operation to continually withdraw gas from the chamber **11**, while gas is continually being supplied to the chamber to maintain it at a constant set pressure. Experimentally, the optimum pressure maintained in the embodiment illustrated has been in the 10–100 micron range.

Once heating of the substance to be melted begins to occur, a significant de-gassing takes place; and this gas is withdrawn by pump **22**. Because the gas within the interior chamber **11** becomes ionized and would produce argon plasma throughout the chamber, it is difficult to confine the electron beam to the area of the crucible unless auxiliary means of focusing are used. The concave shape of the cathode surface will, in itself, provide some small amount of focusing at the pressures and voltages used.

One of the significant teachings of this invention is found in the way in which the electron stream is focused onto crucible **10**. Conically shaped member **16** is employed to provide a mechanical focusing of the electron stream, i.e., the electron flow is electron-optically focused by use of a mechanical member. When a high voltage is applied, via the electrode **18**, between the cathode **15** and the grounded anode **10**, an electric field is established, the lines of which extend between the cathode **15** and the anode **10** in a generally frusto-conically shaped bundle of substantially straight lines converging on the anode **10**. These electric field lines terminate substantially at right angles to both anode and cathode. The potential with respect to ground at any point in this field is proportional to the distance of the point from the anode as measured along the lines. This electric field is always maintained so as to provide a discharge path for the electrons and ions. The electrons substantially follow these electric field lines which focus to the anode **10**, while the ions bombard the concave cathode surface. The cathode then releases electrons by secondary electron emission. These electrons cause further ionization of the argon, resulting in an increased bombardment of the cathode by returning positive ions. This, in turn, causes further secondary emission from the cathode, until that level is reached beyond which the electrons and ions will depress the potential fields so as to restrict further flow. Should the electrons deviate from the electric field lines directed to the anode **10** and hit the inside surface of the focusing cone **16**, secondary emission will result, causing additional electrons to be directed to the anode **10**.

Without the focusing cone **16**, the potential field would partially take the shape of the concave surface **15**, while the outer portion of the potential field in the fringe area adjacent the interior wall of chamber **11** would tend to level off. The potential field would tend to level off more rapidy with increasing distance from the concave surface **15**. The electric field lines would be aligned perpendicular to the potential field and would fill the entire chamber **11** so as to diffuse the focusing of electrons on anode or crucible **10**. Because of the shape of the potential field, not only would the electric field be partially directed away from the anode **10**, but in addition the momentum of the electrons would be of sufficient magnitude to carry said electrons past the anode, thereby missing the target.

In addition, when the focusing cone **16** is not used, argon plasma is produced in the entire inner chamber **11**. The sparking and heating that exists would, in a short period of time, cause the vacuum gasket **13** to loose its sealing characteristics which would cause a degeneration of the furnace. When the focusing cone **16** is used, not only will there be greatly improved focusing, but also the ionization of the argon will be limited to the interior of the focusing cone **16**. There will be no ionization of the argon gas to produce argon plasma in that portion of the chamber **11** outside the focusing cone **16**. This is because the external surface of the dielectric focusing cone **16**, is limited to charging to a voltage below the breakdown voltage of the argon gas. Initially, when the high voltage power supply is turned on, the outside surface of focusing cone **16** does charge up but then is bombarded by ions while electrons go to the base plate **12**. The electrons discharge to ground because of the ground connection of base plate **12**. The ions cause the exterior surface of focusing cone **16** to become more positive such that a voltage less than the breakdown voltage of the argon gas exists. Now, the vacuum gasket will be protected, and of course, improved mechanical focusing is realized. Focusing cone **16**, as shown above, requires no auxiliary sources of electrical power, nor any power at all; rather it is a purely mechanical method requiring no adjustments of any nature.

Referring to FIG. 2, there is illustrated a second mechanical focusing arrangement, comprising conical member **27** and a conical member **28**. Since the density of the electron stream increases greatly as it approaches the apex of the conical member, it causes said apex to heat up to a very high temperature which, in some applications, could cause the bottom of the cone to melt. Thus, there is provided a shortened cone **27** which could be constructed, for example, of Pyrex as above, and a second conical element **28** at the bottom thereof which could be constructed of fused silica or refractory material which could take the increased heating with little deteriorating effect. It would also be possible to provide a single cone having a plural composition. That is, the upper portion thereof could be made of Pyrex, and the lower portion of fused silica or other material having a relatively high melting point.

Of course, as mentioned above, the entire cone could be constructed of fused silica or a refractory material, but this is very costly and not necessary, in view of the embodiment illustrated in FIG. 2. A modification of the focusing cones discussed would be to cool the cones, for example, by making the walls of the cones hollow and causing a cooling fluid to flow therein.

Although the embodiments illustrated are directed toward an electron beam vacuum melting furnace, the principles of the invention could be applied to any arrangement in which electron beam focusing is required, for example, in vacuum tube technology, or a cathode ray tube in which no scan is required. It would also be possible to use the mechanical focusing to focus the electron stream down to a much finer point than is illustrated in the figures, and provide means for moving the beam focus cone, and use the focused stream for thin film machining, or other etching process. It would also be possible to use the mechanically focused beam to heat up a material to provide an ultraviolet or infrared light source, for example, for satellite tracking operations.

Thus, it is to be understood that the embodiments shown are illustrative only, and that many variations and modifications may be made without departing from the principles of the invention herein disclosed and defined by the appended claims.

I claim:

1. An electron-ion beam device, comprising:

means for generating an electron stream, said means comprising:

a cathode,

an anode, and

means including said cathode and anode for maintaining a plasma therebetween, and

means mechanically focusing said electron stream into a path converging on said anode.

2. Apparatus as in claim 1, in which said cathode has a concave surface.

3. Apparatus as in claim 2, in which the focal point of said concave cathode is at said anode.

4. An electron beam device as in claim 1, for heating a substance, in which said anode is a crucible in which the substance to be heated is placed.

5. Apparatus as in claim 4, further including means for cooling said crucible.

6. Apparatus as in claim 1, in which said means for generating an electron stream includes means for maintaining a high voltage between said cathode and said anode.

7. Apparatus as in claim 6, in which said cathode has a hollow interior configuration, further including a cooling fluid disposed within said hollow interior.

8. Apparatus as in claim 1, in which said mechanically focusing means includes a member having a continuously decreasing cross-sectional area.

9. Apparatus as in claim 8, in which said member comprises a heat resistant glass.

10. Apparatus as in claim 8, in which said member comprises a refractory material composition.

11. Apparatus as in claim 8, in which said member comprises a quartz composition.

12. Apparatus as in claim 8, in which said member has a conical configuration.

13. Apparatus as in claim 1, in which said mechanical-focusing means includes a first frusto-conically shaped member having its apex directed toward said anode, and a second member having a portion thereof of a frusto-conical confiuration also having its apex directed toward said anode, said second member being disposed between said first member and said anode.

14. Apparatus as in claim 13, in which the diameter across the apex of said second frusto-conical member is less than the diameter across the apex of said first frusto-conical member.

15. Apparatus as in claim 14, in which said second frusto-conical member comprises a high-temperature, non-electrically conductive material composition.

16. Apparatus as in claim 1, in which said mechanically focusing means is positioned intermediate said cathode and anode.

17. Apparatus as in claim 1, in which said means for maintaining a plasma therebetween further comprises:

walls defining a chamber,

said chamber containing a gas at less than atmospheric pressure, and

means for maintaining a high voltage between said cathode and anode.

18. Apparatus as in claim 17, in which said gas is argon.

19. An electron-ion beam device, comprising:

means for generating an electron stream, said means comprising:

a cathode,

an anode, and

means including said cathode and anode for creating a plasma therebetween, and

means for focusing said electron stream on said anode, said means comprising a member composed of dielectric material and shaped to define a converging path to said anode.

References Cited

UNITED STATES PATENTS

2,793,282	5/1957	Steigerwald.	
2,899,556	8/1959	Schopper et al.	
848,600	3/1907	Von Pirani.	
3,192,318	6/1965	Schleich et al.	
3,311,746	3/1967	Linstrom	250—49.5
3,202,794	8/1965	Shrader et al.	13—31 XR

ROBERT K. SCHAEFER, *Primary Examiner.*

M. GINSBURG, *Assistant Examiner.*