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(54) **Thermoionic emissive cathode method of fabricating the same thermoionic emissive cathode and electron beam apparatus**

Thermisch emittierende Kathode, Herstellungsverfahren einer solchen thermisch emittierende Kathode und Elektronenstrahl-Gerät

Cathode à émission thermoionique, procédé de fabrication d'une telle cathode à émission thermoionique et appareil à faisceau d'électrons

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**materials and their possible application in**  
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## Description

The present invention relates to an electron beam apparatus for melting, bonding, drilling and annealing metal material, etc., to be machined by irradiating the material with electron beam in vacuum pressure in which an effect of ion sputtering is considerable under low vacuum pressure, which electron beam apparatus uses a thermoionic emissive cathode.

A conventional thermoionic emissive cathode for electron beam irradiation is usually made of oxide, lanthanum boride or high melting point metal, etc. For example, as disclosed in the Japanese Institute of Electrical Engineers, Technical Report (Section II) No. 147, pages 1 to 42 (Edited by the Japanese Institute of Electrical Engineers Corporation, April, 1983), a thermoionic emissive cathode in an electron beam apparatus for melting, bonding, drilling and annealing metal material, etc., is made of a high melting point metal such as tungsten or tantalum, or lanthanum boride.

It has been known, however, that such high melting point metal has a large work function. Therefore, when such high melting point metal is to be used as the thermoionic emissive cathode material, it is necessary to heat the high melting point metal to very high temperature. For example, when tungsten is used as a material of a thermoionic emissive cathode of direct heating type, it is necessary to heat it to a temperature as high as 2500 to 2600°C. Therefore, in order to make direct heating easier, the thermoionic emissive cathode has been made from a thin tungsten wire shaped to a hair-pin or from a thin tungsten tape shaped to a ribbon. Alternatively, a thermoionic emissive cathode has been constituted with a tungsten rod and a tungsten filament coil arranged around the rod and the tungsten rod has been heated by electrons emitted from the tungsten coil.

In the direct heating method, however, tungsten material of the thermoionic emissive cathode in the form of filament or thin strip is consumed at a relatively high speed by evaporation thereof during its use. Further, the thermoionic emissive cathode of tungsten is locally drilled within relatively short time by ion sputtering of metal vapor, etc., coming from a material to be machined thereby during irradiation of the latter with electron beam. As a result, it has been necessary to replace the tungsten thermoionic emissive cathode frequently.

In the method of heating the rod type thermoionic emissive cathode of tungsten by electrons from the surrounding tungsten coil, on the other hand, there is a problem that the structure of the cathode itself becomes complicated although it is durable against ion sputtering. There is a further problem in this method that life of the thermoionic emissive cathode depends upon life of the tungsten coil which considerably varied according to an operating vacuum pressure.

On the other hand, when lanthanum boride is used as a material of such thermoionic emissive cathode, a current density similar to that obtained by the thermoi-

onic emissive cathode of tungsten can be obtained by heating the thermoionic emissive cathode to a temperature as low as 1500 to 1800°C. Therefore, it is possible to considerably reduce electric power necessary to heat the thermoionic emissive cathode of lanthanum boride compared with that required for the thermoionic emissive cathode of tungsten.

In the lanthanum boride thermoionic emissive cathode, however, there is another problem that a variation of beam current value with time is large compared with the tungsten thermoionic emissive cathode. There is a further problem that durability of lanthanum boride thermoionic emissive cathode against ion sputtering is very low and so a beam current density distribution is changed with time due to craters formed on the cathode by ion sputtering.

FR-A-2 058 653 discloses a thermoionic emissive cathode using a mixture of a refractory metal having a melting point of more than 2500 °C, and an electron emissive substance selected from oxides of barium, calcium, cerium, strontium or thorium. The mixture is prepared by mixing the components, pressing and final sintering. SU-A-371 632 refers to a tungsten cathode wherein tungsten, as the emissive substance, is modified by addition of 1-30 % yttrium boride and the mixture is pressed followed by heating.

An object of the present invention is to provide a thermoionic emissive cathode which can maintain a stable electron emitting characteristic.

Another object of the present invention is to provide a thermoionic emissive cathode which can emit electrons stably at a low temperature, even if it is used for a long time in a vacuum pressure in which an effect of ion sputtering is large under low vacuum pressure.

A further object of the present invention is to provide a method of fabricating the aforementioned thermoionic emissive cathode.

In order to achieve the above-mentioned objects, the present invention provides an electron beam apparatus as defined by claim 1. The thermoionic emissive cathode used in this apparatus is formed of a sintered mixture including the following first and second substances: the first substance is a high melting point refractory substance durable against ion sputtering having a melting point of at least 2000°C and selected from a group consisting of metals having a melting point equal to or higher than 2400°C, alloys containing these metals mainly, carbides of these metals, borides of these metals, zirconium carbides and zirconium borides; and the second substance is a low work function electron emissive substance selected from borides of a metal selected from a group consisting of lanthanum, yttrium, cerium and cesium. The above-mentioned sintered mixture is produced by mixing the above first and second substances and heating under pressure by hot isostatic pressing.

Thus, the present invention provides an electron beam apparatus which uses the thermoionic emissive

cathode as an electron beam source thereof.

The thermoionic emissive cathode used in the apparatus according to the present invention is formed by impregnating electron emissive substance whose work function is relatively low and whose electron beam current density is high as electron emitting means in an ion sputtering durable refractory substance as means for improving durability against ion sputtering. Therefore, the thermoionic emissive cathode is operable at heating temperature substantially equal to that of the lanthanum boride cathode in an vacuum environment under as low pressure as in the range of  $10^{-2}$  to  $10^{-3}$  Pa. Further, since it is durable against ion sputtering, it is possible to emit electron beam stably for long time under the same condition as mentioned above.

In the electron beam apparatus using the present thermoionic emissive cathode, frequency of replacement of the thermoionic emissive cathode can be reduced. In addition, since thermal load of the thermoionic emissive cathode is reduced, it is possible to improve the stability of the electron beam apparatus.

The present invention will be described in further detail with reference to the accompanying drawings, in which:

Fig. 1 is a sectional view showing a thermoionic emissive cathode for use in the apparatus according to a first embodiment of the present invention; Figs. 2 and 3 are sectional views useful to understand a method of fabricating such a thermoionic emissive cathode by hot isostatic pressing process; Fig. 4 is a graph showing heating and pressing steps in the hot isostatic pressing process of the fabricating method;

Fig. 5 is a sectional view useful to understand a manufacture of the thermoionic emissive cathode by a hot uniaxial pressing process which is not an embodiment of the present invention;

Fig. 6 is a table showing characteristics of a thermoionic emissive cathode used in an apparatus according to a further embodiment of the present invention in comparison with that of a conventional thermoionic emissive cathode;

Fig. 7 is a sectional view showing a thermoionic emissive cathode for use in an apparatus according to a further embodiment of the present invention;

Fig. 8 is a sectional view showing a fabrication step of a thermoionic emissive cathode;

Fig. 9 is a sectional view showing a construction of an electron beam apparatus; and

Fig. 10 is a perspective view of a thermoionic emissive cathode used in the electron beam apparatus shown in Fig. 9.

Embodiments of the present invention will be described in detail with reference to the drawings.

In Fig. 1, a thermoionic emissive cathode 1 used in the apparatus according to an embodiment of the

present invention contains a high melting point refractory substance 2 durable against ion sputtering and an electron emitting substance 3 of boride of a metal which is selected from a group consisting of yttrium, lanthanum, cerium and cesium, having low work function and operable at low temperature (for example, in the order of  $1500^{\circ}\text{C}$  to  $1800^{\circ}\text{C}$ ) under low vacuum pressure (for example, in the range of  $10^{-2}$  to  $10^{-3}$  Pa).

Substance which can be used as the high melting point refractory substance 2 which is highly durable against ion sputtering must have a practical melting point of  $2000^{\circ}\text{C}$  or higher. Particularly, metal having melting point of  $2400^{\circ}\text{C}$  or higher (for example, tungsten, rhenium, osmium, tantalum, molybdenum, niobium and iridium), alloy containing the high melting point metal mainly, carbide of the high melting point metal, boride of the high melting point metal are suitable as the substance 2. Further, zirconium carbide and zirconium boride may be used as the high melting point refractory substance 2, since these substances have melting points equal to or higher than  $3000^{\circ}\text{C}$  although melting point of zirconium is low.

Now, a method of fabricating the thermoionic emissive cathode of the present invention by using hot isostatic pressing (referred to as HIP, hereinafter) will be described with reference to Figs. 2 to 4.

A method of fabricating a thermoionic emissive cathode containing tungsten and lanthanum boride will be described first, as a first embodiment of the present invention. 100 g of tungsten powder having average particle size of  $4\text{ }\mu\text{m}$  and 24.5 g of lanthanum boride powder having average particle size of  $1\text{ }\mu\text{m}$  are dry mixed so that volume ratio becomes 5:5. A pellet 4 having a rectangular parallelepiped shape is obtained by rubber pressing a resulting powder mixture under pressure of about  $2000\text{ kgf/cm}^2$ .

Then, as shown in Fig. 2, the pellet 4 is put in a glass container 5 (for example, glass container available from Pylex) which is softened at a desired temperature (for example,  $770^{\circ}\text{C}$ ). The glass container 5 is further filled with aluminum oxide powder 6 and, after evacuated, encapsulation thereof is performed.

Then, the glass container 5 evacuated and sealed is put in a HIP processing device 7 as shown in Fig. 3 and HIP-processed according to the heating and pressing schedule shown in Fig. 4, resulting in a raw material of a thermoionic emissive cathode. Now, the heating and pressing schedule will be described in more detail. In an initial stage, the glass container 5 is heated to softening temperature  $770^{\circ}\text{C}$  at a rate of  $300^{\circ}\text{C/h}$ . Then, the softening temperature is maintained for 40 minutes to completely soften the glass container 5. As to pressing, the pressure in the HIP processing device 7 is increased up to  $100\text{ kgf/cm}^2$  for 5 minutes after the temperature reaches  $770^{\circ}\text{C}$  and, thereafter, is increased up to  $200\text{ kgf/cm}^2$  for 60 minutes. After a final HIP processing condition of  $1300^{\circ}\text{C}$  and  $1500\text{ kgf/cm}^2$  is attained, the condition is maintained for 90 minutes. In this case,

atmosphere in the HIP processing device 7 is argon gas.

The raw thermoionic emissive cathode obtained by the HIP process is shaped to a desired configuration and used as the thermoionic emissive cathode.

As mentioned, the glass container 5 is used as a container for receiving the pellet 4. However, any container formed of material whose softening temperature is lower than the temperature of the final HIP processing condition may be used. For example, metal such as aluminum, soft steel or copper may be used as material forming the container receiving the pellet 4. When a metal is used as the material of the container for receiving the pellet 4, it is possible to press the container to some extent before the container having the pellet 4 therein is softened in the HIP process.

As mentioned, the container 5 is filled with aluminum oxide powder 6 in addition to the pellet 4. However, it is possible to fill the container 5 with other material than aluminum oxide powder 6. For example, a material such as boron nitride powder or zirconium oxide powder, etc., which is not reactive to the pellet 4 and the container 5, may be used instead of aluminum oxide powder 6. The powder material used to fill the container 5 is selected arbitrarily according to HIP processing condition.

According to the HIP process mentioned above, it is possible to make internal pressing state of the pellet 4 uniform. Therefore, an internal tissue of the pellet 4 obtained by this HIP process is uniform, resulting in a very stable electron emitting characteristics.

The fabrication method of the thermoionic emissive cathode containing tungsten and lanthanum boride has been described. When a thermoionic emissive cathode is fabricated by selecting other substances for the high melting point refractory substance durable against ion sputtering and the electron emissive substance from the previously mentioned substances, the selected substances can be processed similarly to the above-mentioned combination of tungsten and lanthanum boride, except the final HIP processing condition.

A second embodiment in which 100 g of tungsten carbide powder having average particle size of 4.5  $\mu\text{m}$  and 32 g of lanthanum boride powder having average particle size of 1  $\mu\text{m}$  are dry mixed so that volume ratio of tungsten carbide to lanthanum boride becomes 5:5 to obtain a sintered mixture by the HIP process will be described. In this case, after dry mixing these substances, the HIP process is performed for the mixture in a similar manner to the first embodiment under final HIP processing condition of 1400°C, 2000 kgf/cm<sup>2</sup> in argon atmosphere, the condition is maintained for 90 minutes.

A third embodiment in which 100 g of tantalum carbide powder having average particle size of 2  $\mu\text{m}$  and 32 g of lanthanum boride powder having average particle size of 1  $\mu\text{m}$  are dry mixed so that volume ratio of tantalum carbide to lanthanum boride becomes 5:5 to obtain a sintered mixture by the HIP process will be described. In this case, after dry mixing these substances, the HIP process is performed for the mixture in a similar

manner to the first embodiment under final HIP processing condition of 1450°C, 1500 kgf/cm<sup>2</sup> in argon atmosphere, the condition is maintained for 90 minutes.

A fourth embodiment in which 100 g of zirconium boride powder having average particle size of 7  $\mu\text{m}$  and 77.5 g of lanthanum boride powder having average particle size of 1  $\mu\text{m}$  are dry mixed so that volume ratio zirconium boride to lanthanum boride becomes 5:5 to obtain a sintered mixture by the HIP process will be described. In this case, after dry mixing these substances, the HIP process is performed for the mixture in a similar manner to the first embodiment under final HIP processing condition of 1450°C, 1500 kgf/cm<sup>2</sup> in argon atmosphere, the condition is maintained for 90 minutes.

In order that a thermoionic emissive cathode of sintered material has a mechanical strength large enough to withstand stress during shaping and heating processes, the heating and pressing conditions of the HIP process for making a sintered mixture of the high melting point refractory substance durable against ion sputtering and the electron emissive substance should be appropriately changed. Particularly, in the final HIP process, a combination of heating temperature of 1000°C or higher and pressure of 200 kgf/cm<sup>2</sup> or higher is necessary for the following reason. That is, in order to obtain a sintered mixture of the high melting point refractory substance durable against ion sputtering and the electron emissive substance under pressure condition of the HIP process lower than 200 kgf/cm<sup>2</sup>, it must be heated up to a temperature close to a melting point of the electron emissive substance. However, such heating shall substantially degrade the electron emitting characteristics of the electron emissive substance. On the other hand, in order to obtain a sintered mixture of the high melting point refractory substance durable against ion sputtering and the electron emissive substance under temperature condition of the HIP process lower than 1000°C, very high pressure is required. However, it is impossible to obtain a sintered mixture of the high melting point refractory substance durable against ion sputtering and the electron emitting substance under pressure condition of the HIP process of 2000 kgf/cm<sup>2</sup> which is maximum for an usual HIP processing device.

Further, the average particle size of the high melting point refractory substance powder durable against ion sputtering and the average particle size of the electron emissive substance powder are not limited to those described. For example, an average particle size of tungsten, tungsten carbide, tantalum carbide or zirconium boride can be in a range from 1  $\mu\text{m}$  to 10  $\mu\text{m}$  and that of lanthanum boride powder can be in a range from 0.5  $\mu\text{m}$  to 15  $\mu\text{m}$ .

Further, the volume ratio of the high melting point refractory substance durable against ion sputtering to the electron emissive substance of the thermoionic emissive cathode is not limited to 5:5, but to a range from 25:75 to 65:35. It was found that when the ratio of the electron emissive substance in the thermoionic

emissive cathode becomes 95% or more, the high melting point refractory substance of the thermoionic emissive cathode can not play its role and the durability of the thermoionic emissive cathode against ion sputtering becomes dependent on the electron emissive substance. On the contrary, when the volume ratio of the electron emissive substance in the thermoionic emissive cathode is 5% or less, the thermoionic emissive cathode can not emit a necessary amount of electron.

The volume ratio of the the high melting point refractory substance durable against ion sputtering to the electron emissive substance of the thermoionic emissive cathode will be described. For example, when a thermoionic emissive cathode containing tungsten carbide and lanthanum boride is used as an electron beam source of an electron beam apparatus, it is preferable that the volume ratio of tungsten carbide to lanthanum boride is within a range from 25:75 to 65:35, because it is possible to restrict stability of electron beam current from a thermoionic emissive cathode containing lanthanum boride in volume ratio of 35% or more within 3%. And, for a thermoionic emissive cathode containing lanthanum boride in a volume ratio of 75% or more, the durability against ion sputtering is degraded since the ratio of the high melting point refractory substance is reduced. As a result, lanthanum boride is consumed much and an electron emitting surface of the thermoionic emissive cathode retrogrades. With such retrogradation of the electron emitting surface of the thermoionic emissive cathode, a cross-over position formed by an electron gun is deviated. If such deviation of the cross-over position is not adjusted, the electron beam blurs. In addition, electron beam current change is observed, which are very undesirable in view of the electron beam characteristics. Therefore, the volume ratio of lanthanum boride contained in the thermoionic emissive cathode of sintered tungsten carbide and lanthanum boride is preferably between 35% and 75%.

The heating and pressing processes in order to obtain a sintered mixture of the high melting point refractory substance durable against ion sputtering and the electron emissive substance is performed by a HIP process.

A fabrication method of thermoionic emissive cathode by the hot uniaxial pressing process which is not an embodiment of the invention but useful for its understanding will be described with reference to Fig. 5.

Tungsten carbide and lanthanum boride are used as the high melting point refractory substance which is durable against ion sputtering and the electron emissive substance, respectively. 100 g of tungsten carbide powder having average particle size of 4.5  $\mu\text{m}$  and 30 g of lanthanum boride powder having average particle size of 1  $\mu\text{m}$  are dry mixed so that volume ratio of tungsten carbide to lanthanum boride becomes 5:5. A dry-mixed powder 11 is inserted into a graphite mold composed of a graphite punch 8 coated with boron nitride 10 and a graphite die 9. And, a pressure of 500 kgf/cm<sup>2</sup> is exerted

onto the mixture powder 11 in one direction by the graphite punch 8. Then, the mixture powder 11 is heated in a flow of nitrogen gas at a rate of 40°C/min. It is maintained at 1600°C for 1 hour and thereafter cooled in the graphite mold. The mixture powder 11 is pressed to a sintered mixture by this hot uniaxial pressing process.

Fig. 6 is a table showing characteristics of the thermoionic emissive cathode, such as operating temperature, durability against ion sputtering, beam current stability and lifetime, according to a further embodiment of the present invention using a cathode obtained from a sintered mixture of tungsten carbide and lanthanum boride by the HIP process and the conventional ribbon filament type thermoionic emissive cathode and the lanthanum boride thermoionic emissive cathode.

First, temperature of the respective thermoionic emissive cathodes at which beam current becomes 3A/cm<sup>2</sup> is compared.

When the thermoionic emissive cathode according to the further embodiment is heated, it starts to emit electron beam at 1200°C and the beam current of 3A/cm<sup>2</sup> is obtained at which the temperature reaches 1400 - 1450°C. In this case, the electron beam irradiated at  $1 \times 10^{-3}$  Pa.

Contrary to the present thermoionic emissive cathode, in the ribbon filament type tungsten thermoionic emissive cathode, beam current density of 3A/cm<sup>2</sup> is obtained when it is heated to about 2600°C. That is, the thermal load of the thermoionic emissive cathode according to the embodiment is substantially reduced compared with that of the tungsten thermoionic emissive cathode.

The durability of a thermoionic emissive cathode against ion sputtering is observed by irradiating a stainless steel block with electron beam of 40 mA emitted from the thermoionic emissive cathode with acceleration voltage of 60 kV. In the table shown in Fig. 6, the ion sputtering durability is indicated by a ratio of volume of a crater on a surface of the thermoionic emissive cathode drilled by ion sputtering to that of the tungsten thermoionic emissive cathode.

As shown in Fig. 6, the thermoionic emissive cathode according to the further embodiment exhibits substantially the same ion sputtering durability as that of the tungsten thermoionic emissive cathode.

Contrary to the cathode according to the further embodiment, the durability of the lanthanum boride cathode against ion sputtering is as low as about one-tenth of the tungsten cathode as well as the present cathode. Therefore, when electron beam emitted from the lanthanum boride cathode is used, focus of the beam and beam current thereof may be varied considerably with time.

Condition of electron beam was measured by continuously irradiating a stainless steel block with electron beam of 40 mA emitted from each of the thermoionic emissive cathodes with acceleration voltage of 60 kV. The life times of the respective thermoionic emissive

cathodes are compared.

As a result, it is clarified that the thermoionic emissive cathode according to the further embodiment emits electron beam stably at least about 200 hours with beam current stability of about  $\pm 3\%$ .

On the other hand, the life of the tungsten thermoionic emissive cathode is as short as about 50 hours under the same condition and the beam current stability thereof is about  $\pm 5\%$ . The life of the lanthanum boride cathode is about 200 hours under the same condition. In the case of the lanthanum boride cathode, however, loss of the electron emitting surface is considerable, the stability of beam current is about  $\pm 10\%$  and the beam focus is considerably varied with time.

From the results of comparison mentioned above, the superior characteristics of the thermoionic emissive cathode according to the second embodiment over the conventional tungsten thermoionic emissive cathode as well as the conventional lanthanum boride cathode is proved. The comparison results can be applied to not only the thermoionic emissive cathode containing tungsten carbide and lanthanum boride but also thermoionic emissive cathodes containing any combination of high melting point refractory and ion sputtering durable substance and the electron emissive substance both, selected respectively from the previously mentioned substance groups.

Now, a fifth embodiment of the present invention will be described with reference to Fig. 7.

As mentioned previously, in the thermoionic emissive cathode according to the first or further embodiment as described, the electron emissive substance contained therein is evaporated from the whole surface of the cathode when the cathode is heated to high temperature. Therefore, such evaporation of electron emissive substance should be restricted. According to a still further embodiment, a thermoionic emissive cathode is provided with means for restricting evaporation of electron emissive substance from the whole surface area of the cathode.

As shown in Fig. 7, a whole surface of a thermoionic emissive cathode 1 except an electron emitting surface 12 thereof is coated with a coating film 13. The coating film 13 of several hundreds angstrom ( $1 \text{ \AA} = 10^{-10} \text{ m}$ ) thick is formed by depositing tungsten by sputtering. With the coating film 13, it is possible to reduce the surface area of the cathode from which electron emissive substance evaporates and hence reduce the consuming rate of evaporation of electron emissive substance.

Although the coating film 13 is of tungsten in this embodiment, other materials than tungsten may be used therefor provided that their melting point is equal to or higher than  $1400 - 1800^\circ\text{C}$  which is the operating temperature of the thermoionic emissive cathode. Particularly, in view of mechanical strength, etc., of the coating film 13, it is preferable to use any material whose melting point is  $2400^\circ\text{C}$  or higher. Material satisfying such condition other than tungsten may be at least a

metal selected from a group consisting of rhenium, osmium, tantalum, molybdenum, niobium and iridium, etc., at least an alloy containing any of them as its main constituent, at least a carbide of any of them or at least a boride of any of them. In addition, nitrogen boride, aluminum oxide and zirconium oxide, etc., may be used for the coating film 13 as well.

When the coating film 13 is formed of a material containing any of the metals, the coating film 13 can function for long time due to its durability against ion sputtering. It should be noted, however, there is a tendency of electric discharge between the coating film 13 and a grounding electrode, such as anode. This discharge phenomenon causes beam current to vary and hence makes electron beam unstable. On the contrary, when an insulating material or the like such as nitrogen boride, aluminum oxide and zirconium oxide is used as material forming the coating film 13, it is possible to obtain stable electron beam. That is, in this case, it is possible to obtain very stable electron beam since there is no variation of electron beam current due to discharge, although the life of the coating film 13 is not so long as that obtainable with the film of the metal material.

The thickness of the coating film 13 is not limited to several hundreds angstrom and it has been found that an effect of sufficiently preventing evaporation of electron emissive substance is obtained with the film thickness in a range from several tens angstrom to several  $\mu\text{m}$ .

Further, complete uniform deposition of the coating film 13 is not always required. There is no practical problem even if there are some locally undeposited portions.

The deposition of the coating film 13 can be performed by other means than sputtering and CVD (Chemical Vapor Deposition) may be used for the purpose.

A process which is not an embodiment of the present invention but useful for its understanding will be described with reference to Fig. 8.

In Fig. 8, an electron emissive surface 16 of a thermoionic emissive cathode 15 of a sintered mixture of tungsten carbide which is a high melting point refractory and ion sputtering durable substance and lanthanum boride which is an electron emissive substance, prepared by heating and pressing is coated with a film of tungsten boride by which electron emission from lanthanum boride of the cathode is prevented.

In the sixth embodiment of the present invention, the thermoionic emissive cathode 15 of the sintered mixture of tungsten carbide and lanthanum boride, prepared by heating and pressing is put in a dry etching device 14, as shown in Fig. 8 and the electron emissive surface 16 of the cathode 15 is dry etched in a low air pressure maintained at  $10^{-1} \text{ Pa}$  with DC 800V for about one hour to evaporate, sublimate and/or drop tungsten boride on the electron emissive surface 16 by reaction with atmospheric gas to thereby expose lanthanum boride of the electron emissive surface 16.

Although, in order to activate a thermoionic emissive cathode, it is usual to put it in an electron beam apparatus and heat it to about 1400°C for about one hour, it is possible to activate the thermoionic emissive cathode 15 having the dry etched electron emissive surface 16 at about 1400°C for about 5 minutes.

Next, an electron beam apparatus using a thermoionic emissive cathode prepared by hot isostatic pressing process of tungsten carbide and lanthanum boride, according to a seventh embodiment of the present invention will be described with reference to Figs. 9 and 10.

As shown in Fig. 9, an electron gun used in the electron beam apparatus comprises a cathode 17, a bias electrode 18 and an anode 19. The cathode 17 comprises a thermoionic emissive cathode 20 and a pair of heaters 21 and 21' arranged on both sides of the thermoionic emissive cathode 20 for heating the latter. The cathode 17 further comprises a pair of stems 22 and 22' mechanically supporting the heaters 21 and 21' and constituting a circuit for supplying electric current to the heaters 21 and 21' to heat the latter, clamp screws 23 and 23' and an insulating plate 24. That is, the cathode 17 has a structure similar to the Vogel type structure. The thermoionic emissive cathode 20 has a circular electron emissive surface 27 having diameter of 2 - 3 mm, as shown in Fig. 10. A portion 28 which is supplied with electric current directly so as to be heated directly takes in the form of a rectangular parallelepiped block having thickness in current supply direction smaller than in other directions, in order to improve the heating efficiency.

In the electron gun constructed as mentioned above, the thermoionic emissive cathode 20 is heated by conduction of heat from the heaters 21 and 21' and emits an electron beam 25 from the electron emissive surface 27. The electron beam 25 emitted from the electron emissive surface 27 is accelerated by an accelerating voltage applied between the thermoionic emissive cathode 20 and the anode 26, while an amount of beam current of the electron beam 25 is controlled by a beam current control voltage applied between the thermoionic emissive cathode 20 and the bias electrode 18, and passes through an opening 26 of the anode 19 externally.

This electron gun, when heated to about 1500 - 1800°C in vacuum pressure in the range of  $10^{-2}$  -  $10^{-3}$  Pa, can emit electron beam stably.

The scope of the present invention is not limited to the described embodiments and covers other technical matters coming within the scope of the claims.

## Claims

1. An electron beam apparatus for melting metal material, comprising a thermoionic emissive cathode (20) for emitting an electron beam (25) by being heated by conduction of heat from a pair of heaters

(21,21'), an anode (19) for accelerating said electron beam and a bias electrode (18) for controlling an amount of beam current of said electron beam, wherein said thermoionic emissive cathode is formed from a sintered mixture having at least one high melting point refractory and ion sputtering durable substance (2) and at least one electron emissive substance (3) having low work function, characterized in that:

said high melting point refractory and ion sputtering durable substance (2) has a melting point of at least 2000°C and is selected from a group consisting of a metal having melting point equal to or higher than 2400°C, an alloy containing said metal as a main constituent thereof, a carbide of said metal, a boride of said metal, zirconium carbide and zirconium boride, said electron emissive substance (3) is selected from borides of a metal selected from a group consisting of lanthanum, yttrium, cerium and cesium, a volume ratio of said high melting point refractory and ion sputtering durable substance (2) to said electron emissive substance (3) is within a range of from 25:75 to 65:35, and said sintered mixture is prepared by hot isostatic pressing process to render said thermoionic emissive cathode highly resistant to metal ion sputtering occurring during electron beam emission from said thermoionic cathode for melting metal material.

2. The apparatus as claimed in claim 1, wherein said thermoionic cathode comprises means (13) for preventing said electron emissive substance from evaporation from other surface portion than an electron emissive surface (12) of said thermoionic emissive cathode.
3. The apparatus as claimed in claim 2, wherein said means (13) comprises a coating film of a material containing substance having melting point equal to or higher than 2400°C provided on said other surface portion of said thermoionic emissive cathode (20).
4. The apparatus as claimed in claim 2 or 3, wherein said means (13) comprises a coating film of an insulating material.
5. The apparatus as claimed in claim 4, wherein said coating film (13) is formed from a substance selected from a group of nitrogen boride, aluminum oxide and zirconium oxide.
6. The apparatus as claimed in any of claims 1 to 5, wherein said high melting point refractory and ion

sputtering durable substance (2) is tungsten carbide and said electron emissive substance (3) is lanthanum boride.

7. The apparatus as claimed in any of claims 1 to 6, wherein said thermoionic emissive cathode comprises an electron emissive surface (16) formed by dry etching.

## Patentansprüche

1. Elektronenstrahlvorrichtung zum Schmelzen von metallischem Material, mit einer thermisch emittierenden Kathode (20) zum Emittieren eines Elektronenstrahls (25) durch Erwärmen durch Wärmeleitung von einem Paar Heizern (21, 21'), einer Anode (19) zum Beschleunigen des Elektronenstrahls und einer Vorspannungselektrode (18) zum Steuern eines Strahlstrombetrags des Elektronenstrahls, wobei die thermisch emittierende Kathode aus einem Sintergemisch mit mindestens einer hochschmelzenden feuerfesten und ionenzerstäubungsbeständigen Substanz (2) und mindestens einer elektronenemittierenden Substanz (3) mit geringer Austrittsarbeit besteht, dadurch gekennzeichnet, daß:

die hochschmelzende feuerfeste und ionenzerstäubungsbeständige Substanz (2) einen Schmelzpunkt von mindestens 2000 °C hat und aus einer Gruppe gewählt ist, die aus einem Metall mit einem Schmelzpunkt, der größer oder gleich 2400 °C ist, einer Legierung, die das Metall als ihren Hauptbestandteil enthält, einem Carbid dieses Metalls, einem Borid dieses Metalls, Zirkoniumcarbid und Zirkoniumborid besteht, die elektronenemittierende Substanz (3) aus Boriden eines Metalls gewählt ist, das aus einer Gruppe gewählt ist, die aus Lanthan, Yttrium, Cerium und Cäsium besteht, ein Volumenverhältnis zwischen der hochschmelzenden feuerfesten und ionenzerstäubungsbeständigen Substanz (2) und der elektronenemittierenden Substanz (3) in einem Bereich von 25:75 bis 65:35 liegt und das Sintergemisch in einem isostatischen Warmpreßprozeß hergestellt wird, um die thermisch emittierende Kathode hochwiderstandsfähig gegen Metallionenzerstäubung zu machen, die während der Elektronenstrahlemission aus der thermisch emittierenden Kathode zum Schmelzen eines metallischen Materials auftritt.

2. Vorrichtung nach Anspruch 1, wobei die thermisch emittierende Kathode eine Einrichtung (13) zum Verhindern, daß die elektronenemittierende Sub-

stanz von einem anderen Oberflächenabschnitt als einer elektronenemittierenden Oberfläche (12) der thermisch emittierenden Kathode verdampft wird, aufweist.

3. Vorrichtung nach Anspruch 2, wobei die Einrichtung (13) eine Deckschicht aus einem Material aufweist, das eine Substanz mit einem Schmelzpunkt enthält, der gleich oder größer als 2400 °C ist, und das auf dem anderen Oberflächenabschnitt der thermisch emittierenden Kathode (20) vorgesehen ist.

4. Vorrichtung nach Anspruch 2 oder 3, wobei die Einrichtung (13) eine Deckschicht aus einem Isoliermaterial aufweist.

5. Vorrichtung nach Anspruch 4, wobei die Deckschicht (13) aus einer Substanz ausgebildet ist, die aus einer Gruppe von Stickstoffborid, Aluminiumoxid und Zirkoniumoxid ausgewählt ist.

6. Vorrichtung nach einem der Ansprüche 1 bis 5, wobei die hochschmelzende feuerfeste und ionenzerstäubungsbeständige Substanz (2) Wolframcarbid und die elektronenemittierende Substanz (3) Lanthanborid ist.

7. Vorrichtung nach einem der Ansprüche 1 bis 6, wobei die thermisch emittierende Kathode eine elektronenemittierende Oberfläche (16) aufweist, die durch Trockenätzen ausgebildet ist.

## Revendications

1. Appareil à faisceau d'électrons pour fondre une matière métallique, comprenant une cathode (20) à émission thermoionique pour émettre un faisceau d'électrons (25) étant chauffée par conduction de chaleur provenant d'une paire d'éléments chauffants (21, 21'), une anode 19 pour accélérer ledit faisceau d'électrons et une électrode de polarisation (18) pour commander une certaine quantité de courant de faisceau dudit faisceau d'électrons, dans lequel la cathode à émission thermoionique est formée à partir d'un mélange fritté possédant au moins une substance réfractaire (2) à point de fusion élevé et résistant durablement à la pulvérisation cathodique d'ions et au moins une substance (3) émettrice d'électrons possédant un faible travail d'extraction, caractérisé en ce que:

ladite substance réfractaire (2) à point de fusion élevé et résistant durablement à la pulvérisation cathodique d'ions possède un point de fusion d'au moins 2000°C et est choisie dans le groupe formé par un métal ayant un point de fusion supérieur ou égal à 2400°C, un alliage

contenant ledit métal en tant que constituant principal de celui-ci, un carbure dudit métal, un borure dudit métal, le carbure de zirconium et le borure de zirconium.

ladite substance (3) émettrice d'électrons est choisie parmi les borures d'un métal choisi dans un groupe formé par le lanthane, l'yttrium, le cérium et le césium, un rapport volumique de ladite substance réfractaire (2) à point de fusion élevé et résistant durablement à la pulvérisation cathodique d'ions à ladite substance (3) émettrice d'électrons est compris entre 25:75 et 65:35, et ledit mélange fritté est préparé par un procédé de pressage isostatique à chaud pour rendre la cathode à émission thermoionique très résistante à la pulvérisation cathodique d'ions métalliques se produisant au cours de l'émission d'un faisceau d'électrons à partir de ladite cathode à émission thermoionique pour fondre de la matière métallique.

2. Appareil selon la revendication 1, dans lequel ladite cathode à émission thermoionique comprend un moyen (13) pour empêcher la vaporisation de ladite substance émettrice d'électrons d'une partie de surface autre qu'une surface (12) émettrice d'électrons de ladite cathode à émission thermoionique.
3. Appareil selon la revendication 2, dans lequel ledit moyen (13) comprend un film de revêtement d'une substance contenant une matière ayant un point de fusion supérieur ou égal à 2400°C fournie sur ladite autre portion de surface de ladite cathode (20) à émission thermoionique.
4. Appareil selon la revendication 2 ou 3, dans lequel le moyen (13) comprend un film de revêtement d'une matière isolante.
5. Appareil selon la revendication 4, dans laquelle ledit film de revêtement (13) est formé à partir d'une substance choisie dans le groupe formé par le borure d'azote, l'oxyde d'aluminium et l'oxyde de zirconium.
6. Appareil selon l'une quelconque des revendications 1 à 5, dans lequel la substance réfractaire (2) à point de fusion élevé et résistant durablement à la pulvérisation cathodique d'ions est le carbure de tungstène et ladite substance (3) émettrice d'électrons est le borure de lanthane.
7. Appareil selon l'une quelconque des revendications 1 à 6, dans laquelle la cathode à émission thermoionique comprend une surface (16) émettrice d'électrons formée par une attaque chimique à sec.

Fig. 1

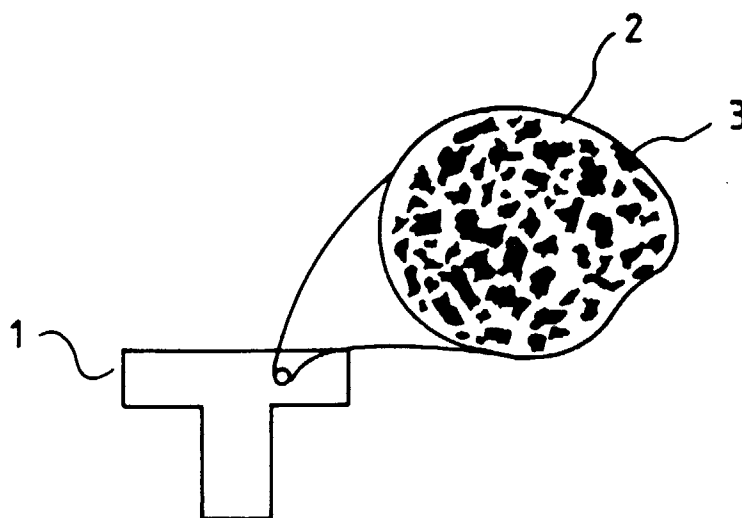
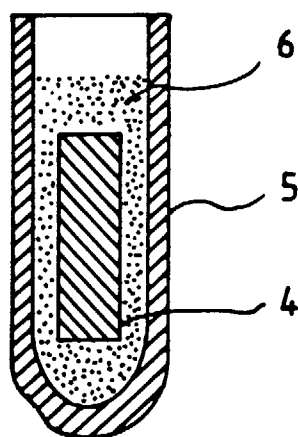


Fig. 2



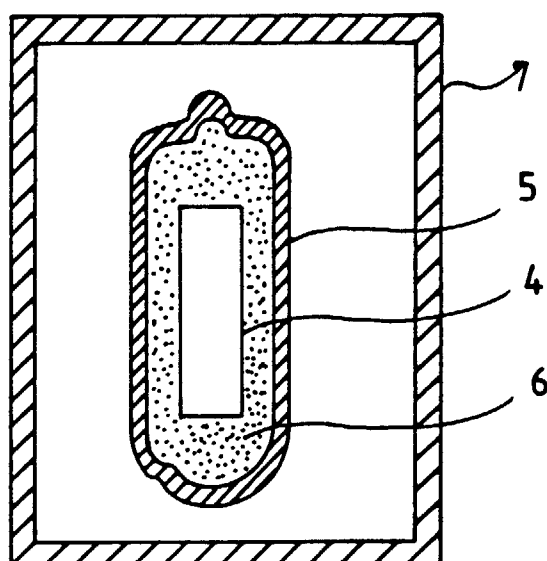


Fig. 3

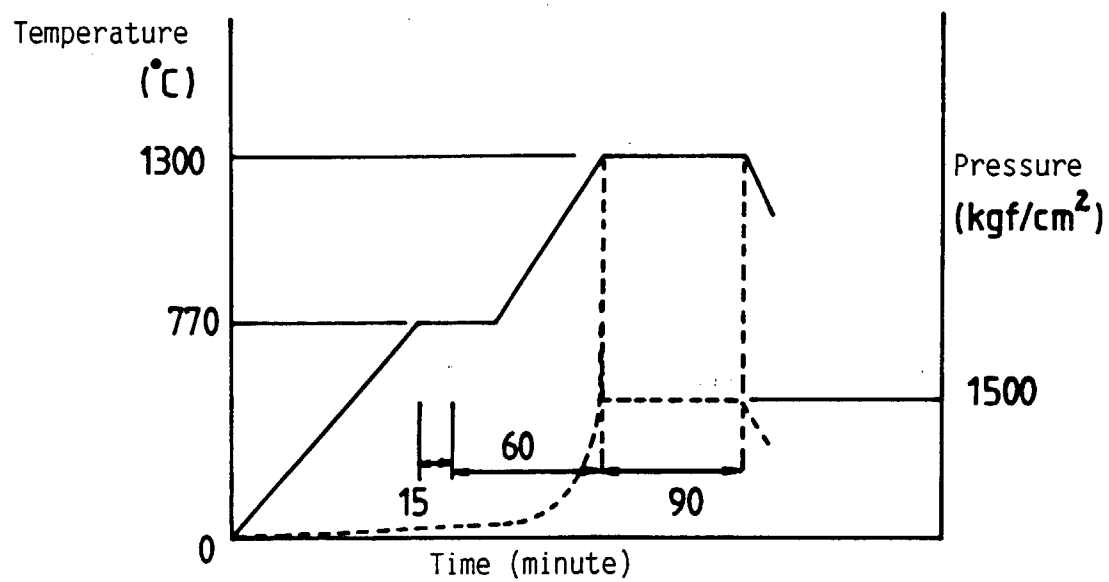


Fig. 4

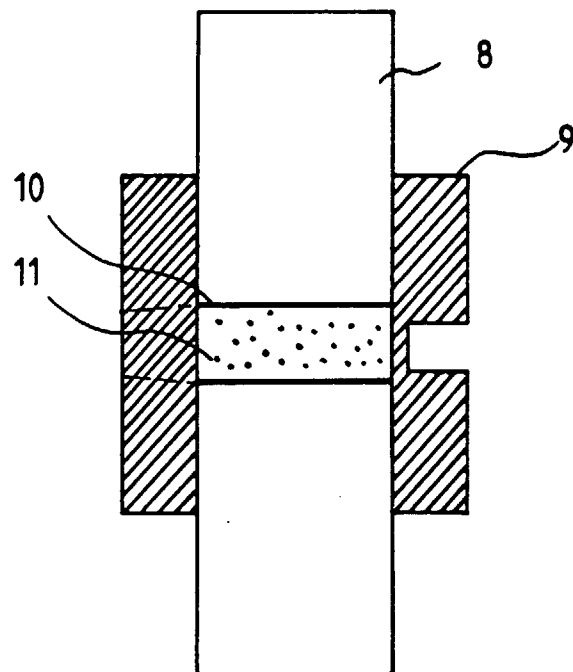


Fig. 5

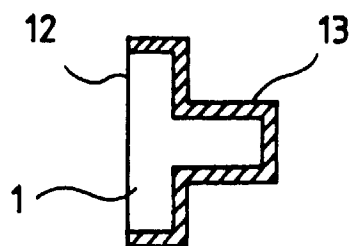


Fig. 7

Fig. 6

|                                      | A ribbon filament<br>type tungsten<br>thermoionic<br>emissive cathode | A lanthanum boride<br>thermoionic<br>emissive cathode | The thermoionic<br>emissive cathode<br>according to the<br>second embodiment |
|--------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------|------------------------------------------------------------------------------|
| Operating<br>temperature             | 2600 °C                                                               | 1400~1500 °C                                          | 1400~1450 °C                                                                 |
| Durability against<br>ion sputtering | 1                                                                     | ~10                                                   | ~1                                                                           |
| Beam current<br>stability            | ± 5 %                                                                 | ± 10 %                                                | ± 3 %                                                                        |
| Lifetime                             | 50 h                                                                  | 200 h                                                 | 200 h                                                                        |

Fig. 8

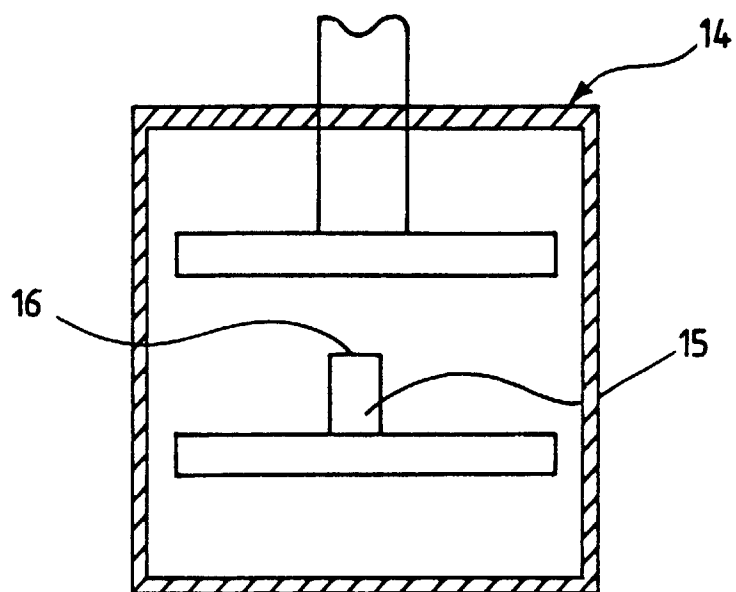


Fig. 9

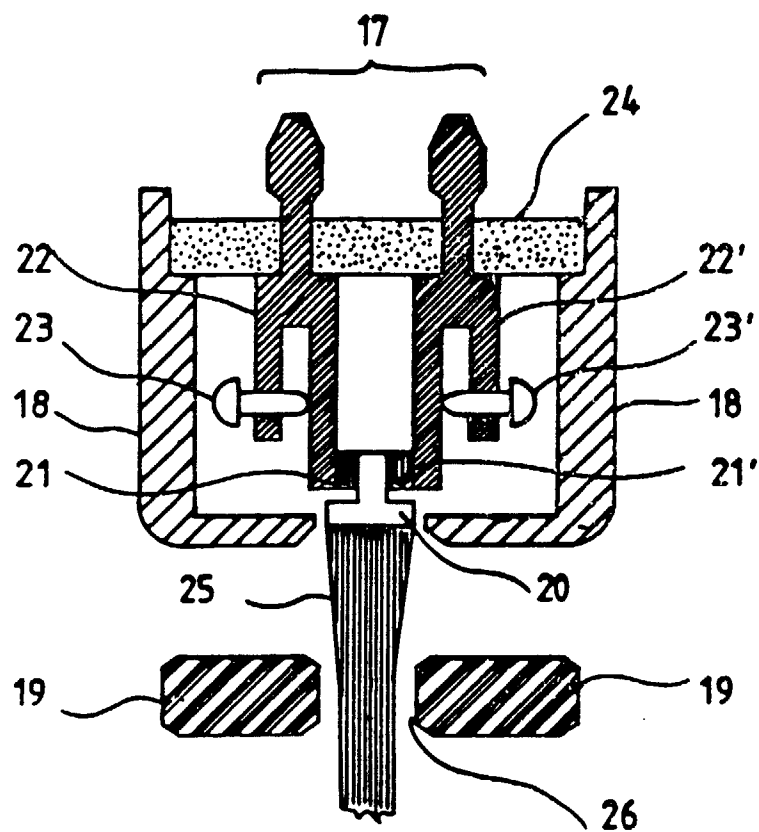


Fig. 10

