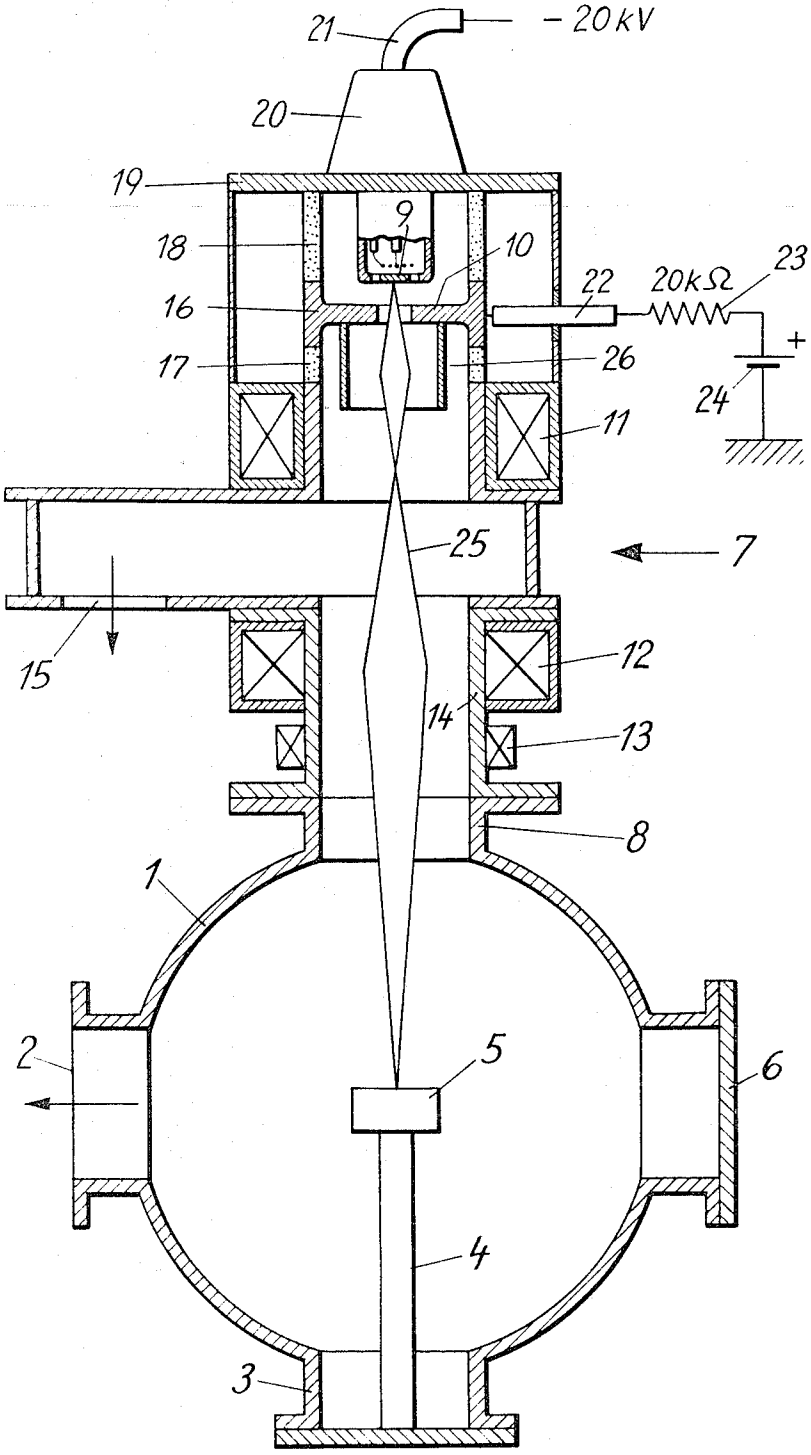
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ELECTRON BEAM TUBE WITH ION SHIELD

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# ELECTRON BEAM TUBE WITH ION SHIELD

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This invention relates to high-performance electron beam apparatus for use in melting and evaporization of substances in vacuum or for the machining of work pieces. The well-known electron gun used for the production of electron beam consists fundamentally of an electron emitting cathode, an acceleration electrode for the acceleration of electrons being emitted from the cathode to high velocities and a system of electron lenses for focusing the emerging electrons into a beam. It is also customary to provide a deflection arrangement to provide control of the direction of the beam exiting from the aperture of the electron gun. Since the production of an electron beam must be observed in a good vacuum, an evacuation apparatus is joined onto the electron gun.

It is known that an electron beam can be brought into the free atmosphere through a suitable number of separated and pumped pressure steps or through a window closed with a thin aluminum foil where the beam is then at one's disposal for processing purposes. Such a beam can, for example, be used to drill, mill and weld work pieces. These techniques have recently attained importance in the fabrication of very delicate instrument parts of high melting materials. The proportionately small range of the electron beam in air is inconvenient so that in actual practice the electron gun, one or more, is combined with an evacuable work chamber which is indispensible if the intended processing of treatment of the work piece or the purity thereof requires a vacuum such as, for example, the vacuum melting of metals or the out gassing thereof, or the vacuum evaporation of substances for the production of thin films on substrates.

In most electron beam equipment, the evacuable work chamber and the housing of the electron gun are grounded as a safety precaution, while the cathode is kept at a high negative potential with respect to the housing and ground.

The acceleration electrode, normally a simple orifice opposite the cathode, is also usually at ground potential. The cathode space is usually evacuated separately from the rest of the equipment. The walls of the work chamber and the housing of the electron gun within which the grounded accelerated electrode is located, define a space surrounded on nearly all sides by surfaces of the same potential (standand or reference potential or ground potential). The electron beam passes through the opening of the acceleration electrode into the aforementioned space and therein strikes the material to be processed or the work piece whereby the inherent kinetic energy of the electrons is changed into the heat and thus causes the heating of the material.

In such electron beam apparatus positive ions will be formed as the result of the unavoidable ionization of the residual gas molecules by the electron beam. These positive ions will be produced in the cathode space and will be joined by those ions arriving via the opening in the acceleration electrode. These ions in the cathode space will be accelerated toward and will strike the cathode with a very high velocity which results, as is well known, in intensive cathode sputtering and consequent destruction of the cathode. This is particularly true in such electron beam apparatus where new gas outbursts occur during the processing procedure or where one



intentionally works at higher pressure to minimize gas outburts or to compensate for a space charge. The life of the cathode in a high-capacity electron beam apparatus was up to now very limited and unpredictable often lasting only a few hours. Also it is not possible to increase the number of operating hours, before replacement of the cathode is required, by the use of a so-called disk cathode in which a tungsten disk is indirectly heated by means of an electron-emitting auxiliary cathode to such a temperature that it itself emits electrons in sufficient quantity. The positive ion problem causes comparatively fast destruction of the cathode in the normal case and even faster destruction at the high cathode temperatures which are necessary for high-power beam operation.

In order to retard the fast destruction of the cathode through positive ion bombardment, it has been heretofore proposed that an electron gun be used which incorporates the principle of ion separation through deflection. In this gun the planes of the cathode and the acceleration electrode (anode) are arranged to be inclined in opposite directions at a predetermined angle with reference to the axis of the subsequent focusing lenses. These two angles are so set specified that the electron beam, according to the dependence on the acceleration space, remains on the system axis. A compartment-like separation of the positive ions is produced by the acceleration field according to their masses, electrical charges and energy range whereby most of the ions no longer strike the emission surface of the cathode but rather the Wehnelt cylinder surrounding the cathode. Magnets have been proposed to perform the deflection in connection with the separation of the ions. With such an arrangement, the tendency for the formation of craters on the cathode surface can be greatly reduced; but the arrangement possesses the disadvantage of requiring complicated and highly accurate construction. It has been shown that protection provided the cathode by this arrangement is still inadequate in applications requiring longer operating periods when strong gas bursts (which are unavoidable especially with metallurgical applications) are likely to occur in the worn chamber. It is an object of the present invention to overcome the aforementioned difficulties in a manner which will become apparent from the following description of the invention.

The high-power electron beam apparatus of the present invention for the heating of materials under vacuum and especially for the melting, evaporation or processing of materials comprises an evacuable work chamber and at least one electron gun, including an electron emitting cathode and an acceleration electrode, connected to it wherein the cathode is at negative potential with respect to the walls of the work chamber and is characterized by the provision of an ion screen electrode on the side of the cathode toward the work chamber, said ion screen electrode being insulated from the walls of the work chamber and disposed at a positive potential with respect to the walls of the work chamber.

An apparatus according to the present invention will be explained in detail by the following written description taken in connection with the accompanying drawing. The figure shows a work chamber 1 that can be evacuated through the connecting piece 2. On another connecting piece 3 there is flanged a jig 4 for a piece of material to be processed with the electron beam. A crucible 5 may be provided to hold the melting charge or a work piece to be processed by the electron beam. Depending on the treatment or process desired, other auxiliary arrangements may become necessary as the occasion demands and may be mounted on the blind flange 6. Since the special kind of treatment or process cannot be determined for the general description of the invention under discussion, the kind of auxiliary arrangement that might

be provided at 6 will not be further discussed herein. The invention has utility in providing high-power operation for all electron beam apparatus discharging into an evacuable work chamber.

The electron gun 7 supported on the connecting piece 8 serves to illustrate the means for obtaining high power operation. It shows essentially in a well-known manner, a cathode part 9, an acceleration electrode 10 and electromagnetic or electrostatic focusing and deflection system 11, 12, and 13 which focuses the electrons from the cathode and directs them onto the desired place on the raw material or work piece 5 to be treated. The housing 14 of the electron gun has its own pump-out connection 15 which serves to maintain a good vacuum in the gun even if the vacuum in the work chamber is temporarily impaired, for example through gas bursts from the heated work material.

The described electron beam apparatus embodying the invention is different from the known equipment in that an ion stream electrode (an electrode analogous to ion screen) is provided and indeed in the present embodiment the acceleration electrode 10 is itself formed as such. The combined ion screen-acceleration electrode is electrically insulated from the rest of the house of the electron gun and for this purpose is supported on a ring 16 which with similar ring shaped insulators 17 and 18 adjacent to it on both sides form a vacuum tight housing wall. Numeral 19 designates a closure plate which carries the cathode structure. The cathode is connected with a high potential source, for example 20 kv., through the cable 21 above the insulator 20. The insulated acceleration electrode 10 on the other hand as shown in the drawing, is connected by the symbolically drawn electrical resistance 23 of about 20 kilo ohms to the positive terminal of a potential source 24 while the negative terminal is grounded. In the simplest case a battery may be used as the potential source. Potentials of about 100 volts upwards have been used very successfully. Also a high positive potential of a few kilovolts can be used. Lower potentials are sufficient with well-evacuated work chambers wherein little outgassing of the work piece 5 occurs, whereas higher potentials are preferred in applications embodying strong gas outbursts in the work chamber. If one uses higher positive potentials on the acceleration electrode which in the present embodiment is formed as an ion screen electrode, one gains the further advantage that the beam current which can be drawn from the cathode can be made greater thereby increasing the power of the electron beam over that otherwise obtainable from similar construction having similar operating restrictions without increasing the penetration ability of the X-rays produced.

The positive ion screen-acceleration electrode of the present invention apparently operates to prevent the positive ions in the space of beam 25 (hereinafter referred to as the "beam space") and those ions from the work chamber from entering the cathode space. This result is not obtainable by a simple positive aperture as previously proposed. The result is obtained by a cylindrically formed ion screen electrode 26 with its axis parallel to the direction of the electron beam or with a combination of the aperture and cylinder as shown in the drawing.

The resistance 23 acts as a protection resistance in case an undesired discharge should occur between the cathode and the acceleration electrode. If such protection against arcing is not taken destruction of the cathode may result. The resistance 23 limits the discharge current flowing to the ion screen electrode to a sale value. With previously known arrangements in which the acceleration electrode was not insulated and was at ground potential, a protection must be installed in the high potential lead 21 which will rapidly interrupt conduction at large current strengths. On the other hand the conductor 21 must carry the same working current as the maximum permitted beam current without interruption. The required protection must be very sensitive and accurate since the maximum permissible beam current may amount to a few amperes and scarcely higher than this is the not to be exceeded current which would cause a discharge between the cathode and the acceleration electrode. That kind of electron beam apparatus required repeated replacement of the high potential protection resulting in additional expense of operation which is avoided by the electron beam apparatus embodying the protective resistance 23 according to the present invention.

According to the previously predominate theory that it is primarily the ions being formed in the cathode space (the space between the acceleration electrode and the cathode) which caused the fast destruction of the cathode, only those ions which directly undergo an acceleration through the electric field lying between the cathode and the acceleration electrode could accordingly contribute to the damaging of the cathode. The previously proposed precautions for separation of ions acts only on those ions which find themselves in the cathode space but has no effect to hinder the invasion of ions from the beam space into the cathode space. Since the ions that are formed in the beam space as well as those in the work space find themselves in an electrically neutral space surrounded by equipotential surfaces it is to be expected that few of them can arrive solely as the result of diffusion through the opening in the acceleration electrode to the cathode space and accordingly it appears that special precautions for the exclusion of these few ions from the cathode space would be superfluous.

The exhaustive investigations which led to the present invention has shown that these prior theories are not correct, but that a far greater part of the ions formed in the beam and work space arrive in the cathode space through the acceleration electrode than is possible solely on the basis of diffusion and that correspondingly the effect of this portion of the ions are of importance in limiting the life of the cathode.

This surprising effect presumably finds its explanation in that the electron beam, as a result of its space charge, acts as a channel for the positive ions in which the ions can only escape through the sides by overcoming a potential gradient whereas in a lengthwise direction they would be led into the cathode space through the acceleration electrode as though in a tube. This probably explains why the ion separation arrangements up to the present have been comparatively ineffective in eliminating the greater part of the harmful ions from the path of the electron beam in the cathode space. The persistent remainder is the result of the undisturbed penetration of the ions from the beam and work space is always still too large. On the other hand the ion screen electrode according to the present invention produces so strong a throttling effect on the ion screen penetrating into the cathode space from the beam and work space because of its positive potential that without requiring any further precautions the life of the cathode can be increased manyfold. The investigations up to the present time have demonstrated that at least a ten-times improvement in the life span is obtainable. It has been shown experimentally that an arrangement embodying the present invention can bring about the described ion separation in a cathode space and also that it is easily possible to hold the distance between the cathode and the acceleration electrode so small that the harmful portion of the ions originating in these spaces is no longer significant so that the invention produces a cost reduction as well as a technical advance.

I claim:

1. In an electron beam apparatus for melting, vaporizing or machining material in an evacuable work chamber having a conductive wall, a cathode:

means for connecting said cathode with a potential which is highly negative with respect to the walls of the work chamber;

an apertured acceleration electrode comprising a flat plate spaced from said cathode;

a cylindrical shaped ion screen electrode integrally and electrically connected to said acceleration electrode about said aperture on a side away from said cathode with the axis of said ion screen electrode parallel to the electron beam;

insulating means for mounting integral connected assembly consisting of said acceleration electrode and said ion screen electrode;

means for connecting said acceleration and ion screen electrodes with a potential which is positive with respect to the walls of the work chamber.



2. The electron beam apparatus of claim 1 wherein: said means for connecting said electrodes with a positive potential includes protective resistance means.

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