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THERMIONIC CONVERTER

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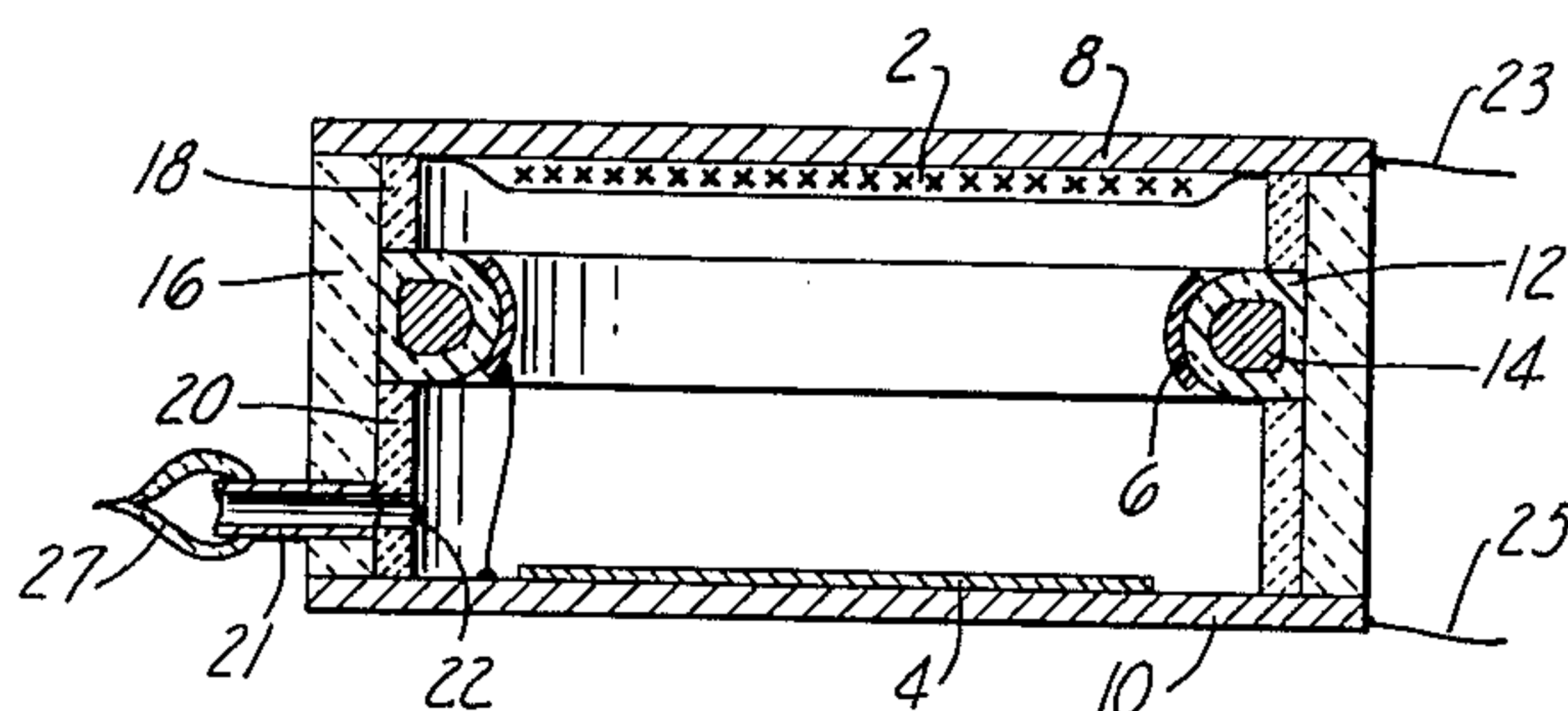


Fig. 1

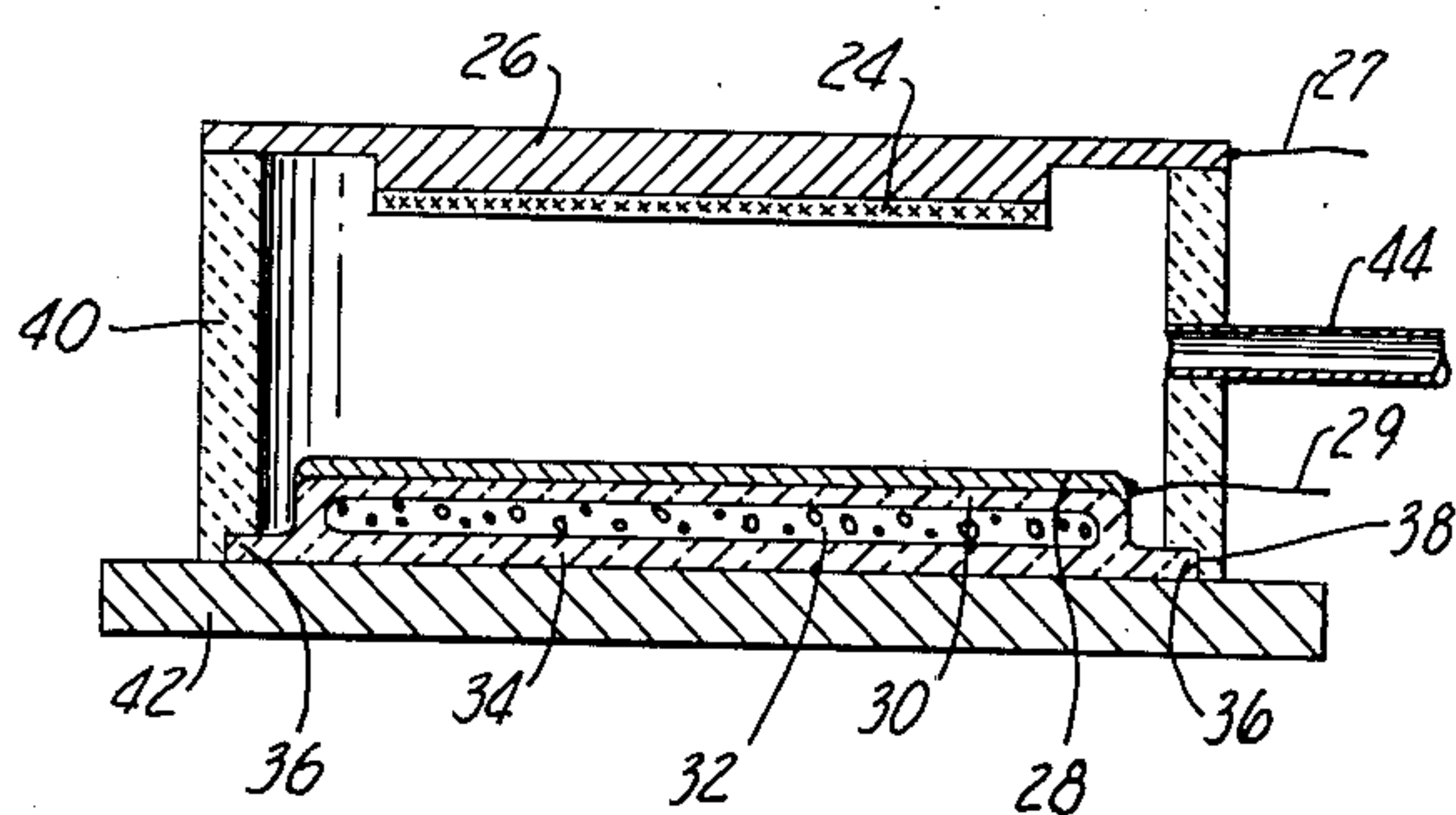


Fig. 2

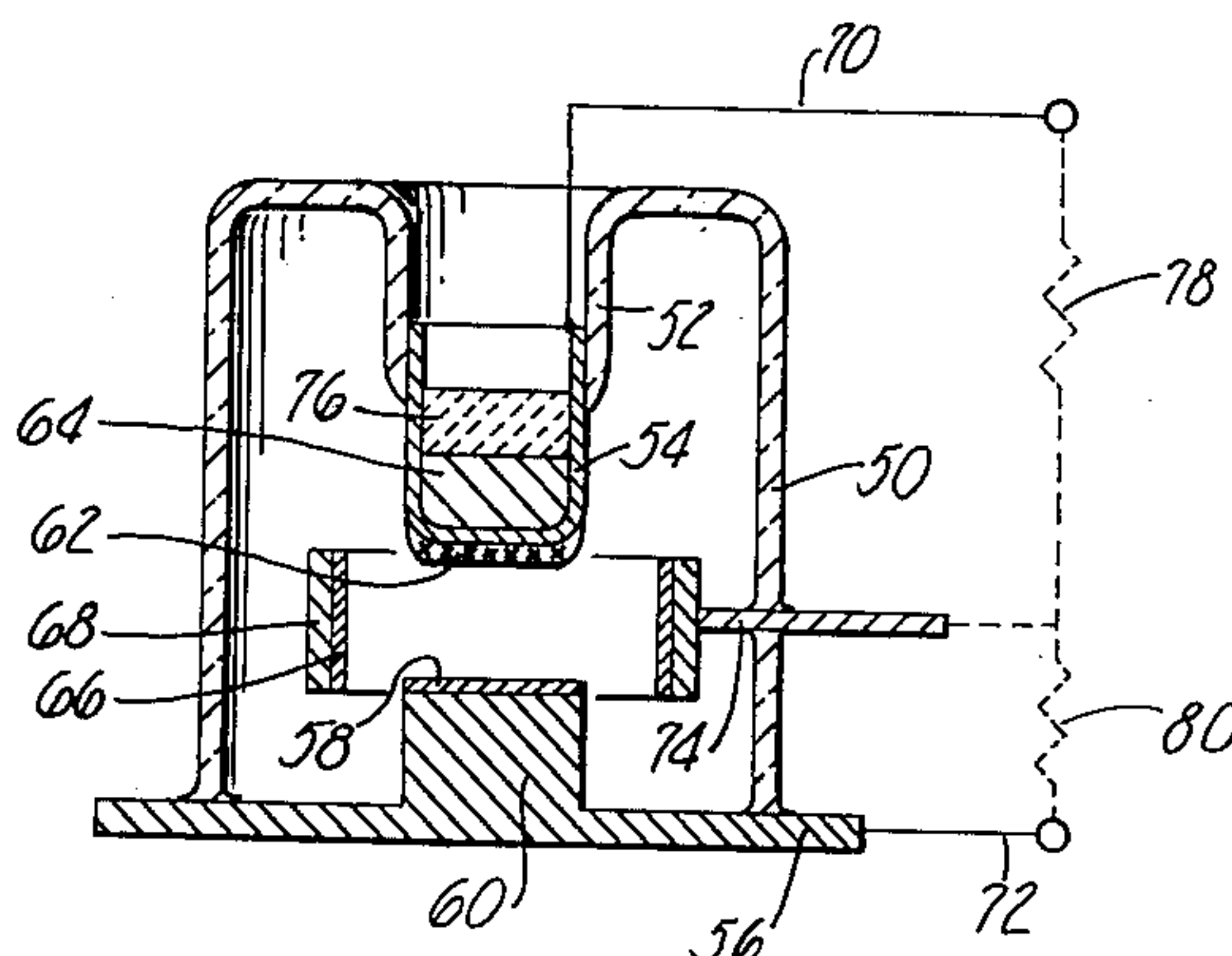


Fig. 3

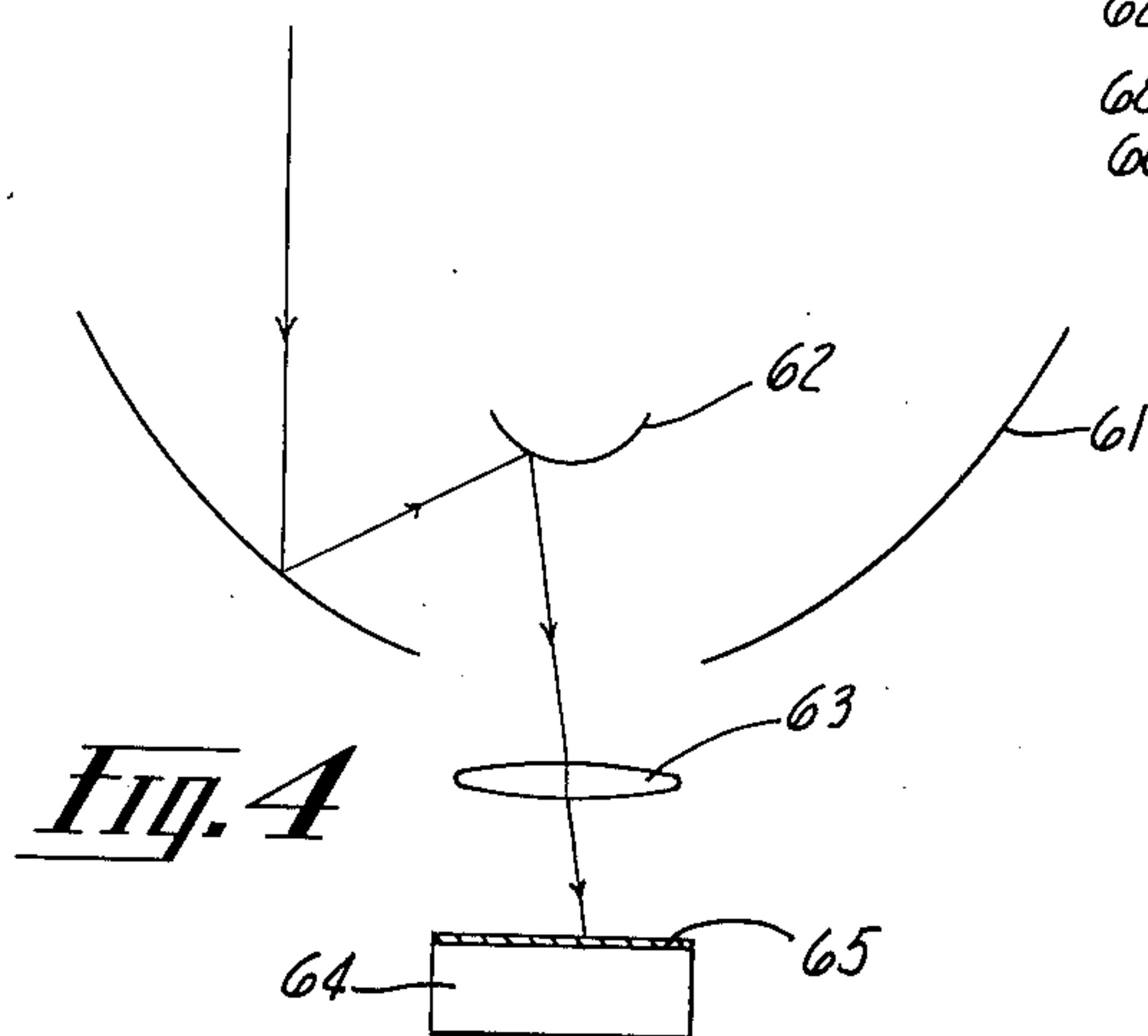


Fig. 4

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THERMIONIC CONVERTER

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This invention relates to new and improved thermionic converters. More specifically the invention relates to thermionic converters of the type in which electrons, thermionically emitted by a heated substance are collected and made available as useful electrical energy.

It is known that thermal energy may be converted into useful electricity by heating a substance which emits electrons when heated and by collecting the emitted electrons on a suitable electrode and thus making the electronic energy available as useful electricity. Attempts to produce efficient conversion of heat into electricity by this means, however, have been complicated by the effect of the electron cloud or space charge which develops between the emitter and collector electrodes. This space charge arises as a consequence of the low kinetic energies of most of the emitted electrons which enables the mutual repulsion of electrons on electrons to be effective and develop a potential minimum between the cathode and anode. It is also known that the accumulation of the space charge may be avoided by reducing the spacing between the emitter and collector surfaces so as to leave no room in the interelectrode space for the development of a substantial electron cloud. Alternatively, it is also known that the space charge may be effectively neutralized by utilizing a gas to fill the interelectrode space, which gas, becoming ionized, neutralizes the space charge.

There are many disadvantages attendant upon the use of these expedients for overcoming the space charge barrier. For example, it has been found that interelectrode spacings, in order to be effective in vacuum devices, must be very small, preferably less than 0.001 inch. Such spacings are exceedingly difficult to maintain with electrodes of the substantial surface area required for the generation of useful quantities of power. Not only are such spacings difficult to provide at the outset, but they are prone to short circuiting due to variations in thermal expansion coefficients between materials employed, as well as due to change in dimension of an unpredictable nature of the large surfaces necessarily involved.

When gas fills are utilized between the electrodes to neutralize the space charge, substantial power losses occur as a consequence of the voltage drop which appears across the interelectrode plasma. In addition, the work function of the cathode must be higher than the ionization potential of the fill gas in order to produce a significant number of ions. High work function cathodes require high operating temperatures to produce electron emission and have high rates of evaporation. Thus, when the neutralizing gas fill comprises cesium vapor, for example, (a material having one of the lowest ionization potentials), a material having a higher work function (3.9 electron volts) and relatively poor emission characteristics must be used. Other alkali metals, such as rubidium and potassium, have even higher work functions (4.2 and 4.3 electron volts, respectively).

This invention, on the other hand, by utilizing a low temperature, thermionic ion source and by providing a controlled, local supply of such ions, permits the utilization of wider interelectrode spacings, while, at the same time, maintaining essentially vacuum conditions in the interelectrode space so as to reduce losses due to voltage drop across the plasma. More specifically, the invention utilizes a thermionic electron emitter preferably one which has a low work function, which may be excited by any

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convenient heat source, and which provides a copious source of electrons when so excited, a collector electrode for collecting the emitted electrons, and a thermionic ion emitter for supplying neutralizing ions to the interelectrode space.

Reference is now made to the following description and to the attached drawings for a fuller understanding of the teachings of the invention.

In the drawings:

FIG. 1 is a view in cross-section of one embodiment of the invention in which a thermionic converter is supplied with neutralizing ions from an auxiliary, thermionically emitting structure;

FIG. 2 is a view in cross-section of another embodiment of the invention in which a thermionic ion source also serves as a collector electrode in a thermionic converter;

FIG. 3 is a view in cross-section of still another embodiment of the invention; while

FIG. 4 illustrates the manner in which the high efficiency of converters built according to the invention may be effectively employed in a converter for solar radiation.

The illustrative embodiment of FIG. 1 employs as its principal elements thermionically emissive surface 2 for emitting electrons, collector electrode surface 4 for collecting electrons emitted by emitter surface 2 and positive ion emitter surface 6. In the preferred embodiment of the invention, thermionic electron emitter surface 2 comprises an oxide coating containing strontium oxide, barium oxide, etc., applied to a large central area of disc-shaped, nickel electrode 8. It will be understood that the coating may comprise any convenient mixture of carbonates, such as strontium carbonate and barium carbonate, applied to emitter electrode 8 by conventional techniques and broken down by heating to produce a mixture of free metals, oxides, and carbonates to form an active, electron-emissive coating after the manner of oxide coated cathodes employed in vacuum tubes. While the oxide coating is to be preferred, since copious electron emission may be obtained at relatively low emitter electrode temperatures, it will be understood that other electron emission substances may be employed such as, for example, tungsten, or tantalum, thoriated tungsten, etc. Also the use of pure metal emitters may be required where poisoning of oxide or thoriated surfaces by material deposited by the ion source may occur. In the event that a pure metal emitter is employed, of course, no supplemental, emissive coating is required since the surface of the metal itself emits the electrons.

In the preferred embodiment of the invention, electron collector surface 4 comprises a layer of cesium on silver oxide laid down over the active portion of silver collector electrode 10 by any means well known in the art. This type of alkali coating is preferred because of its low work function. The use of cesium by itself would produce a surface work function of about 1.9 electron volts, whereas the use of the silver oxide substrate reduces this value. Low work functions suitable for the collector surface can also be obtained by using alkali metals with an antimony base such as sodium antimonide (Na_3Sb), potassium antimonide (K_3Sb), and rubidium antimonide (Rb_3Sb), all of which have work functions of the order of 1.6 electron volts. Still lower work functions may be obtained with multi-alkali surfaces such as the cesium-sodium-potassium-antimony compound $\text{Cs}(\text{NaK})_3\text{Sb}$.

Positive ions for neutralizing space charge accumulating between emitter surface 2 and collector surface 4 are provided by means of a second thermionic emitter surface 6. In the preferred embodiment of the invention ion emitter surface 6 comprises an extremely thin layer of platinum, evaporated onto the desired active surface portion of glass sheath 12. Glass sheath 12, in turn, surrounds platinum wire 14, which is disposed annularly around the active interelectrode space. The thin walled

glass sheath or tube 12 is made of potassium glass (sodium free) and the surface of platinum wire 14 has been coated, after sealing into the glass but prior to subsequent coating with platinum surface 6, with essentially pure potassium, by electrolysis in a bath of molten potassium. Electrical connection can be made to wire 14, if desired, by a lead-in (not shown) through glass sheath 12 to apply a potential to wire 14 to assist the electrolysis and for use in biasing wire 14 during operation of the converter. One mode of operation of a biasing potential is described in connection with FIG. 3.

The various elements of the thermionic converter described above are maintained in position relative to one another by means of a cylindrical hermetic enclosure 16 to which the margins of source electrode disc 8 and collector electrode disc 10 are hermetically sealed by means of a suitable ceramic to metal seal. The annular structure which comprises the thermionic ion emitter is maintained in spaced relation along the axis of the assembled device between emitter and collector electrodes 8 and 10 and girdling the interelectrode space therebetween by means of source electrode spacer ring 18 and collector electrode spacer ring 20. Spacer rings 18 and 20 may be conveniently made of any material having thermal characteristics suitable for maintaining the temperature of ion source layer 6 at the desired working temperature relative to emitter surface 2. The hermetic enclosure provided by means of source electrode 8, collector electrode 10 and ceramic enclosure body 16 may be evacuated by means of exhaust tubulation 21 which is hermetically sealed into the body of ceramic enclosure 16. A breather aperture 22 provided in collector spacer ring 20 provides continuity of vacuum connection between the space within the hermetic enclosure and exhaust tubulation 21. It will be understood that for operation of the device within the earth's atmosphere, normal vacuum tube processing procedures, culminated by permanent closure of exhaust tubulation 21 will be followed in order to obtain a high vacuum within the device. Where, as in some applications, the device will be used in outer space, tubulation 21 may be provided with a frangible closure 27 which may be broken after arrival of the converter in the outer space environment where it is expected to operate. Thus, during space operation, a long life and a high degree of freedom from contamination may be obtained by virtue of the continual pumping of the enclosure which results from its presence in the vacuum of outer space.

Operation of the device is as follows: Heat, supplied from the desired source, such as direct or focused rays of the sun, an exothermic chemical reaction, or a nuclear fission reaction is supplied to the outer surface of emitter electrode 8, raising it to a temperature of approximately 950°. At this temperature copious electron emission from thermionic electron emitter surface 2 is achieved and electrons proceed across the interelectrode space towards collector electrode surface 4 where they are collected and become available as electrical energy. The electrical energy may be transferred from emitter surface 2 and collector surface 4 to a load by means of leads 23 and 25. Neglecting potential drop in the cathode-anode space, the electron current can be drawn with an output potential equal to the difference in work function between the cathode and anode ($2.5-1.9=0.6$ volt). However, as a consequence of the mutual repulsive action of electrons at low velocity, a space charge or electron cloud begins to form in the interelectrode space reducing the output current. Meanwhile, heat radiated by emitter plate 8 and conducted by emitter spacer 18 has been gradually warming ion emitter surface 6 to the point at which positive ions are generated. For the illustrated positive ion source, this temperature will be in the neighborhood of 600° C. This occurs because, as a consequence of the application of heat, potassium migrates electrolytically from its storage place on the surface of platinum wire 14

through the potassium glass wall 12 covering platinum wire 14 to platinum ion emitter surface 6. Due to the high work function of platinum surface 6, the arriving, migratory potassium atoms are each stripped of an electron prior to evaporation from surface 6 into the interelectrode space. While the supply of positive ions thus generated is not nearly as large as the number of electrons emitted by emitter surface 2, this number of ions is adequate to neutralize part of the space charge since an electrostatic balance in the space charge region is not required. This is because little recombination of ions and electrons occurs in a high vacuum and because of the electrodynamics of the particle motion. Since the ratio of the velocities of the electrons and ions is inversely proportional to the square root of their masses, the velocity of the ions in the interaction space is lower than that of the electrons and the ion current required for complete neutralization of the space charge is proportionally reduced. The heaviest ions are thus seen to be the most effective.

As an incident to the process of space charge neutralization, migratory potassium ions eventually deposit on emitter surface 2 and collector surface 4 where they serve to depress the surface work functions, increasing emitter electron emission in the one case and lowering the collector surface potential barrier in the other case. Reduction of cathode work function increases emission current but reduces the output potential for saturation current since the contact potential between cathode and anode is reduced. As the output power depends on the product of current and voltage, the desired output power and internal impedance will, of course, determine the final engineering design. Internal impedance can be adjusted by varying the work functions of the cathode and anode. In general, the higher the emitter surface work function relative to collector surface work function, the higher the internal impedance. It should be understood that the cathode (emitter surface) work function can be higher, equal to or lower than the anode (collector surface) work function but that the higher value is to be preferred.

The principles of the invention may be applied to a second type of structure, as shown in FIG. 2. In this embodiment, thermionic electron emitter surface 24 is mounted upon cylindrical emitter electrode 26 and so placed directly opposite combination electron collector and ion emitter surface 28. As before, electron emissive surface 24 may be an oxide coating, while combined ion emitter and electron collector surface 28 is a platinum film. As before, ion emissive surface 28 comprises a thin coating of platinum overlying a layer 30 of potassium glass through which potassium atoms may migrate from potassium reservoir 32. Potassium reservoir 32 thus takes the form of a glass ampoule having the configuration of a hollow pancake, one surface of the ampoule being thin to promote migration of the potassium within the ampoule to the surface, while the reverse surface portion is substantially thicker to lend mechanical strength and reduce diffusion of potassium. Glass ampoule 34 may be conveniently provided with flange-like peripheral portion 36 adapted to be received in recess 38 of cylindrical ceramic hermetic enclosure wall 40. As before, emitter electrode 26 is hermetically sealed to tubular ceramic enclosure 40, the opposite end of the cylinder being, in turn, sealed to base plate 42. As before, provision is made for evacuating the enclosure by means of exhaust tubulation 44. Base plate 42 is made as large as necessary to operate as a heat sink for maintaining collector surface 28 below the temperature at which it emits electrons.

In operation, heat supplied to thermionic electron emitter surface 24 produces a copious quantity of electrons, while the heat radiated from emitter 24 and the kinetic energy of the emitted electrons raises thermionic ion emitter surface 28 to the necessary temperature for the

production of potassium ions. Potassium ions on the surface of emitter-collector electrode 28 serve to lower its work function and potassium deposited on the surface of emitter surface 24 similarly lowers its work function. Due to the low work function on platinum collector-emitter surface 28, electrons emitted thermionically by emitter surface 24 have sufficient energy to be collected. A charge therefor accumulates on the collector. Since positive ions are, at the same time, being ejected by the collector surface 28 into the interelectrode space, these ions are attracted by the electric field of the space charge until the negative space charge potential is raised.

Many other positive ion sources and thermionic electron emissive materials may be employed in lieu of the materials specifically described above. For example there are many positive ion emitting salts, alkali metal salts, halides, etc. which are known to be useful as positive ion producers. So long as contamination of the ion emission is avoided, as is particularly the case in the illustrative embodiments where the ionic constituent must traverse a glass membrane, many of these sources may be substituted. Where the glass filtering action is desired, all that is required is to select a glass having a natural content of the material whose ions are desired and which is free of other, like, alkali constituents. Cesium or sodium may be used for this purpose, for example.

Other ion sources of course may be employed. For example, the combination of platinum, coated with ferric oxide containing 1.0 percent of aluminum oxide, and a like percentage of an oxide or nitrate of the desired alkali ion supplying metal may be used. When ion sources constructed in this way are operated at a dull red temperature, positive ion emissions of 10^{-4} amperes per square centimeter may be attained. The use of this ion-alkali oxide thermionic ion emitter is illustrated in FIG. 3 in a structure in which heat from a nuclear reaction is utilized to excite thermionic emission for the generation of electricity.

In the structure of FIG. 3, generally cup-shaped cylindrical enclosure member 50, which may be of quartz or of other, well-known refractory insulating material, is provided at its closed end with a reentrant cavity comprising integral cylindrical reentrant portion 52 and metal source electrode cup 54. The mouth, or open end of enclosure member 50 is hermetically closed by means of metal collector electrode 56 which preferably has a sufficiently large mass to maintain the temperature of collector surface 58 below the temperature at which it emits electrons. Low work function collector surface 58 is located on central, cylindrical, collector electrode boss 60 so as to be positioned opposite thermionic electron emitter surface 62 on the flat, innermost portion of emitter electrode cup 54. Emitter electrode cup 54 contains a body 64 of radioactive material of high specific activity, such as polonium, which emits sufficient heat as a consequence of its radioactive decay processes to raise the temperature of electron emitter surface 62 to thermionic temperatures. Nuclear heat source 64 is maintained in position within electrode cup 54 by means of low heat conductivity plug 76, which may be of ceramic, sealed to the inner surface of cup 54. As before, emitter surface 62 may comprise an electron-emitting oxide coating. Thermionic ion emitter surface 66 is of the ferric oxide type described above and it and its annular, platinum support electrode 68 are centered around the space between emitter surface 62 and collector surface 58 so as to supply positive ions to the surrounded space. Ion emitter electrode ring 68 is maintained in position by means of radial support 74 hermetically sealed through the wall of closure member 50, the entire structure being designed to have low thermal mass and low heat loss by conduction, etc.

Operation of the device is similar to that described above in which heat, radiated by emitter electrode 54,

raises the temperature of ion emitter surface 66 to produce thermionic emission of positive ions. Further, the temperature may be controlled or adjusted by varying the secondary heating effect produced by electron impact upon ion emitter surface 66. For this purpose, resistors 78 and 80 (shown in dashed lines) may be connected in series between electron emitter output lead 70 and collector electrode support lead 74 so as to provide a voltage divider for biasing ion emitter electrode 68 to favor collection of electrons from emitter 62. Since the flow of electrons to this surface will produce heat as a consequence of electron impact and of I^2R heating, the degree of heating so achieved may be controlled by changing the potential of ion emitter surface 66 by varying the relative proportions of resistors 78 and 80.

Similarly, many other geometries and thermodynamic arrangements may be employed while applying the teachings of the invention. For example, it may be necessary to employ a supplemental heat sink or radiator in conjunction with the collector electrode in order to maintain suitable temperature gradients within the structure for obtaining the desired operating temperature for the ion source, while at the same time minimizing thermionic electron emission of the collector or collector ion source. Similarly, while planar geometries have been employed for reasons of simplicity of exposition, it will be apparent to those skilled in the art that cylindrical geometries, for example, may be employed in order to best utilize the energy provided by some heat sources and that still other geometries will be better suited for other heat source configurations.

To illustrate an alternative mode of employment of converters fabricated according to the teachings of the invention reference is made to FIG. 4 which schematically shows a typical solar collector system adapted for use with the thermionic converter. The parabolic mirror 61 collects solar radiation and focuses the collected radiation on second mirror 62. The light is transmitted by the mirror to converter 64. A third lens 63 can be utilized to adjust the focus; however as the converter can operate at lower temperatures than other converters requiring a high work function cathode to produce neutralizing ions, a large diameter image may be used and lens 63 may be unnecessary. Optically absorbing, non-reflecting coating 65, such as is afforded by a coating of graphite particles, can be bonded to the outer surface of the cathode of the converter 64 to increase heat absorption.

Because of the variety of application of which the teachings of the invention are capable, the below appended claims should be interpreted in keeping with the spirit of the invention, rather than merely limited to the specific embodiments described herein.

I claim:

1. A thermionic electric generator having an electron emissive cathode for emitting electrons in response to the application of heat, an anode for collecting electrons emitted by said cathode, a substantially gas-free space between said cathode and said anode, a thermionic ion source heated by heat derived from said cathode for supplying neutralizing ions to said space, a heat conducting body between said cathode and said ion source for establishing a temperature gradient therebetween, and electrical connections for connecting said anode and said cathode to a useful load.

2. A thermionic electric generator having an electron emissive cathode for emitting electrons in response to the application of heat, an anode for collecting electrons emitted by said cathode, said anode including a surface heated by said cathode for emitting positive ions and maintaining its own work-function-reducing coating, a substantially gas-free space between said cathode and said anode for permitting passage of electrons from said cathode to said anode and for receiving neutralizing ions from said anode surface, and electrical connections for connecting said cathode and said anode to useful load.

3. A thermionic electric generator having an electron emissive cathode for emitting electrons in response to the application of heat, an anode for collecting electrons emitted by said cathode, a substantially gas-free space between said cathode and said anode, a thermionic ion source heated by radiation and electron bombardment from said cathode for supplying neutralizing ions to said space, a voltage divider for maintaining said ion source at an electron collecting potential, and connecting leads for connecting said cathode and said anode to a useful load.

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