Nov. 3, 1964 L. L. HARING ETAL 3,155,849

THERMIONIC CONVERTER

Filed March 20, 1962

Fig. 2.

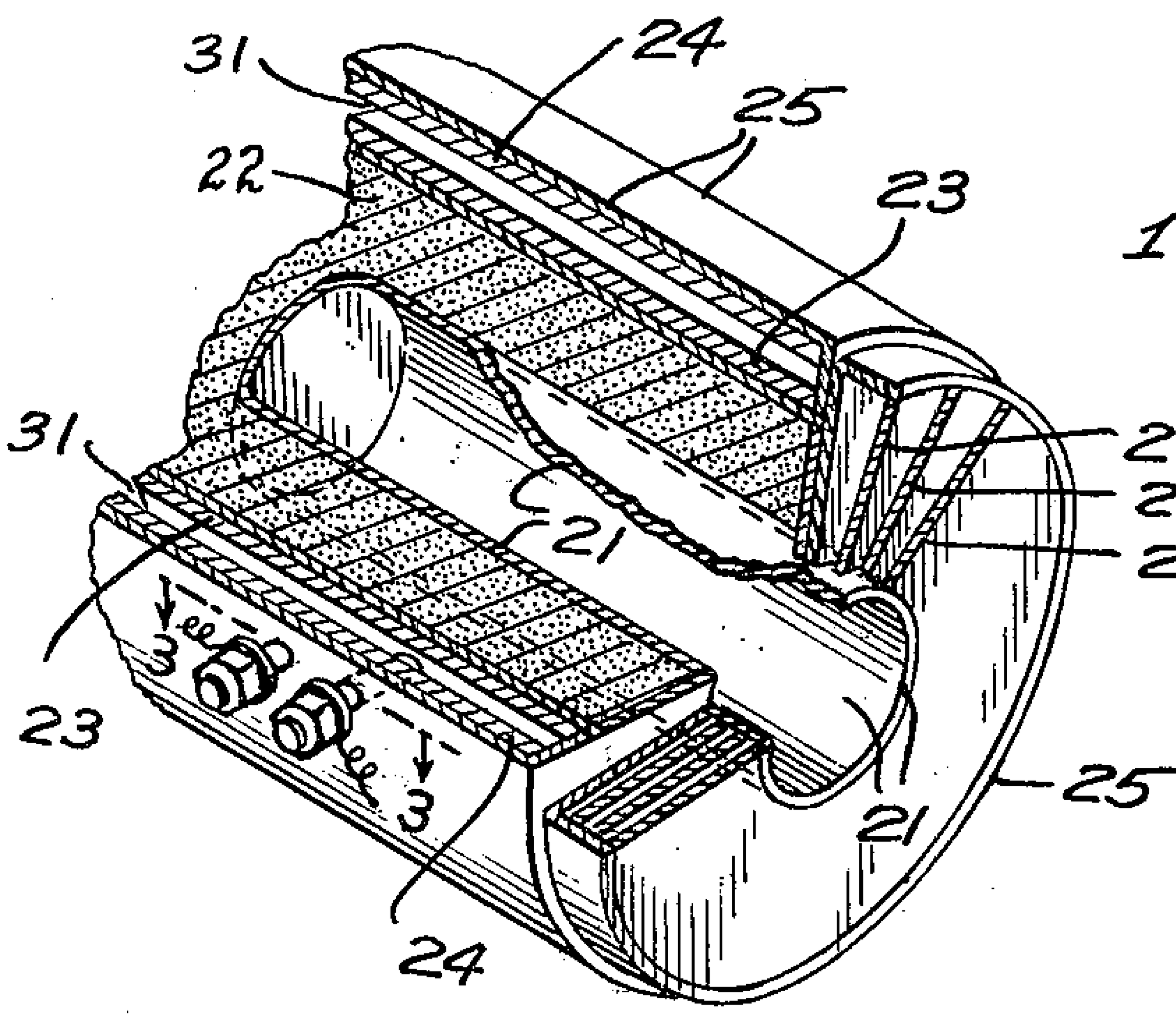
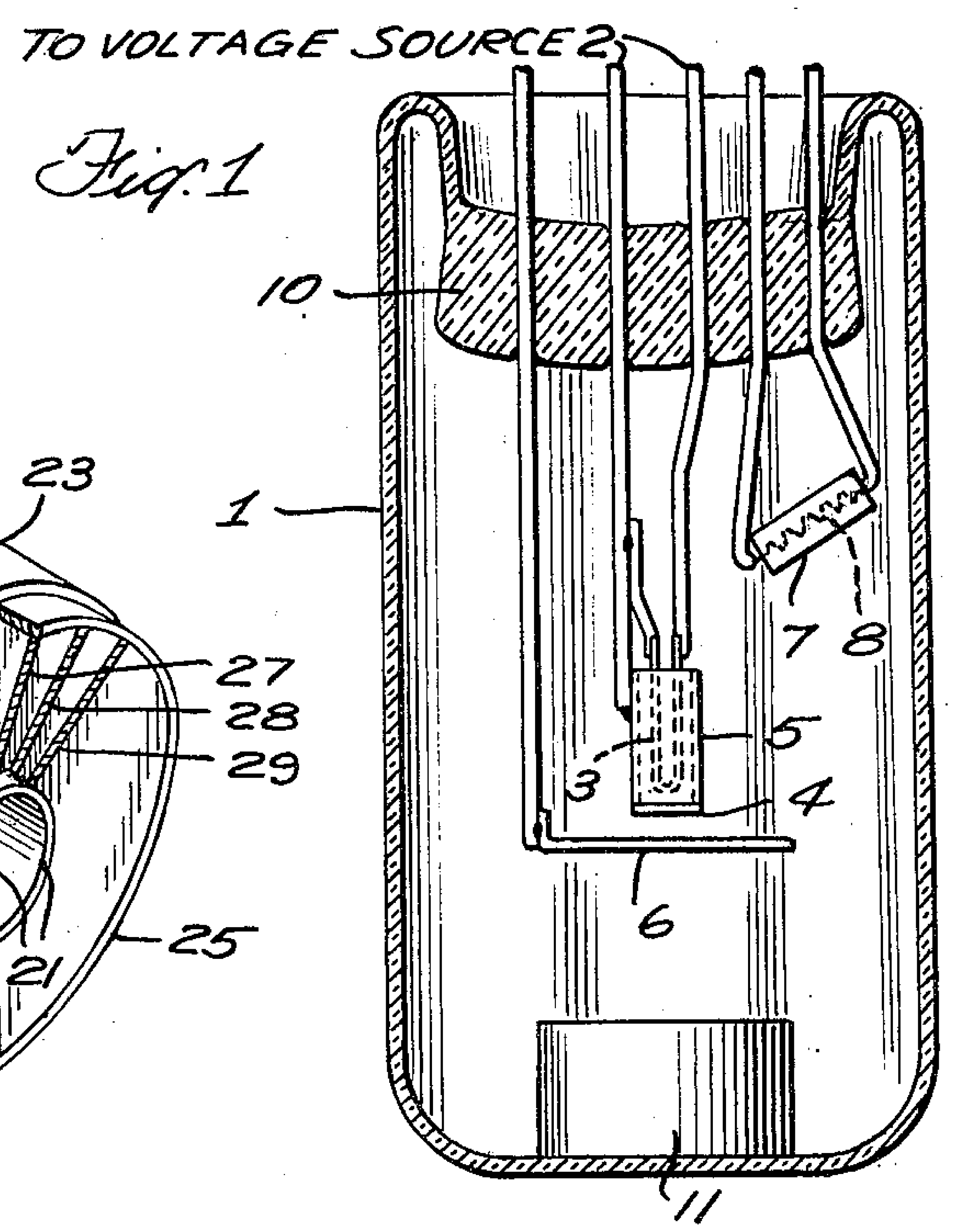


Fig. 1



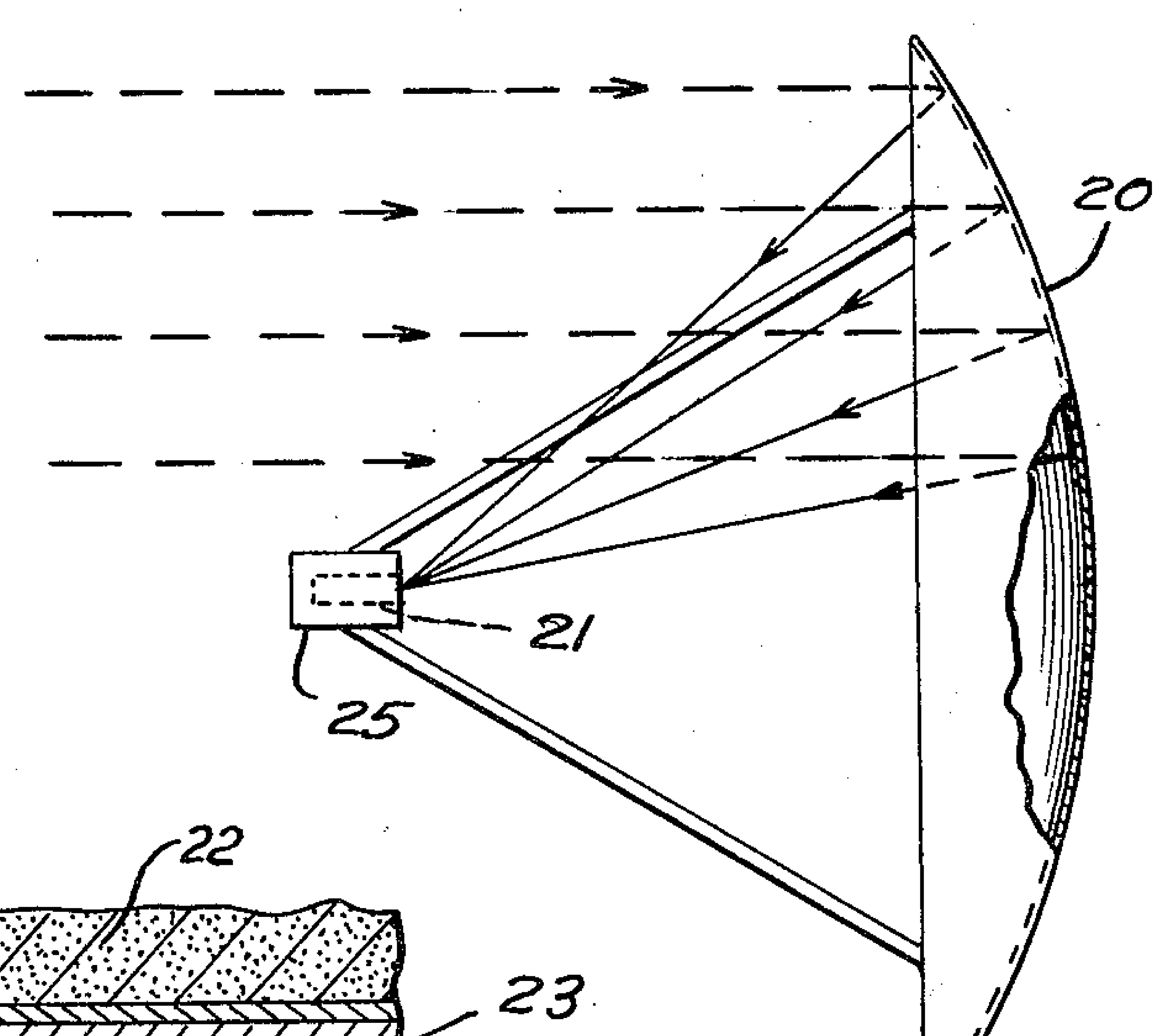
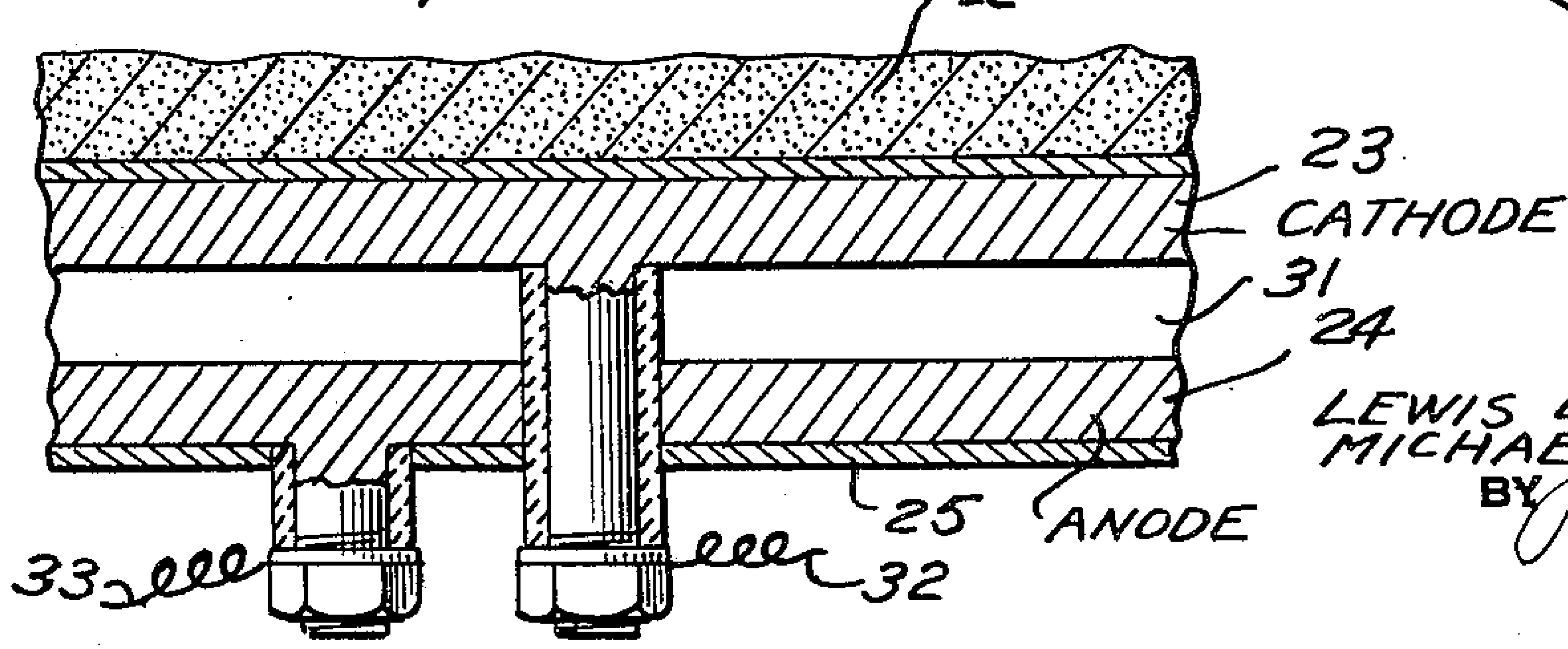


Fig. 4.

Fig. 3.



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3,155,849
THERMIONIC CONVERTER

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This invention relates to voltage generators and particularly to transducers capable of efficiently converting heat to electricity. This application is a continuation-in-part of our application Serial No. 72,501, filed November 29, 1960, and now abandoned.

Thermionic converters are handicapped in operation by reason of the so-called space charge effect which serves to reduce electron flow between their cathode and anode with the result that the plate current is too low to be usable. This effect has been partially overcome by mounting the two electrodes close together or by heating the device to a high temperature and by using cesium vapor in the device which becomes positively ionized on contact with the cathode. The current is carried by electrons but if positive ions are used to neutralize space charge then the cathode in the device is required to have a high work function as compared with the ionization potential of the cesium. According to the present concept of invention, there is effected an improvement in thermionic converters which employs cesium vapor by utilizing a low work function cathode and preferably an additive gas to facilitate ionization of the cesium so that the ionization energy is attained principally from the energy of the electron stream. The improved converter has the advantages of high power density and efficiency coupled with relatively low temperature operation and moderate electrode spacing.

One object of the invention is to provide an efficiently operating device for the direct conversion of heat to electricity.

Another object of the invention is to provide a thermionic converter having high power density.

Other objects and advantages of the invention may be appreciated on reading the following description of one embodiment which is taken in conjunction with the accompanying drawings in which:

FIG. 1 illustrates schematically the thermionic converter;

FIG. 2 illustrates a thermionic converter operable on solar heat;

FIG. 3 is a fragmentary section on enlarged scale taken on line 3—3 of FIG. 2; and

FIG. 4 shows a combination solar energy collector and thermionic converter.

The thermionic converter 1 is operated in conjunction with a voltage source 2 which is directly connected to the aluminum oxide, tungsten coated heater 3 for the cathode electrode 4 of the converter. The cathode consists of a barium impregnated porous tungsten disc which is supported by a molybdenum sleeve 5, the cathode having therefor a low work function. Impregnated tungsten is preferred on the basis of its operating temperature, 1500° K., its ease of machining, its mechanical strength, its resistance to poisoning and its high emission density (10–20 amps.-cm.^{2}). However, other materials may compose the cathode to give it high emission density and low work function. Such materials may be oxide cathodes, impregnated tungsten, or impregnated nickel. A cathode composed of these materials would have a low work function relative to the ionization potential of cesium. An anode 6 of molybdenum is spaced from the cathode at about one-tenth of an inch therefrom. An aluminum oxide gas generator 7 is supported in proximity to the electrodes and has contained therein a coil of tungsten wire 8 which is connected to a source (not shown). The assembly is contained within a sealed Pyrex envelope 8 the sealed top press section 10 of which receives the required electrical connections. A nickel capsule 11 containing cesium chromate and silicon is disposed within the envelope being used as a source of metallic cesium. After assembly the converter is connected to vacuum pumps, baked out and pumped down to about 10^{-6} mm.

To operate the thermionic converter, the cathode is activated by heating and a momentary positive potential relative to the cathode is applied to the anode. R–F radiation is then used to heat the cesium-chromate capsule to produce a chemical reaction which releases metallic cesium vapor. The entire assembly may be placed in an oven heated to less than 200° C., for example 180° C., the cesium, therefore, being under low pressure which means that the mean free path of electrons in cesium is sufficiently long as not to require that the electrodes be closely spaced. If a resistive load is now placed between the cathode and anode and a momentary positive potential relative to the cathode is applied to the anode, electrical power will be generated by the converter and dissipated in the resistive load. However, by electrically heating the aluminum oxide tube to temperatures of about 1500° C. for a few minutes, the electrical power and therefore the efficiency of conversion can be increased considerably. The increased efficiency resulting from the positive ionization of the cesium, which is required to reduce interelectrode space charge effect, is facilitated. It is believed that the additive, i.e., gases released by aluminum oxide when heated, serves to depress the effective ionization potential or electron affinity of the cesium so as to facilitate the ionization of the cesium. Complete neutralization of the space charge may be expected because under these conditions, the positive ions are created in the interelectrode space. When performance begins to deteriorate due to cleanup of the gases, reheating the aluminum oxide tube, particularly to higher temperatures than previously reached, will reactivate the process.

It is also believed that additive gases when employed in the presence of cesium atoms or cesium ions tend to lower the work function of the anode surrounded by such gases.

The heat source 2 is in this case a voltage source, the resistive heater 3 for the cathode being electrically connected thereto. However, there are numerous other heat sources which can usefully be combined with the thermionic converter including nuclear reactors, solar power and chemical fuels. An example of a solar converter is illustrated in FIG. 2. The converter is a cylindrical device and has a single cathode anode cell. A solar heat collector 20 mounted on the device (as shown in FIG. 4) is adapted to reflect the sun's rays into the hollow core of the converter which is the furnace tube 21. Surrounding the tube 21 is a beryllium container 22 which is capable of absorbing and holding the heat brought to the inner tube by the collector. Cylindrically arranged about the beryllium container 22 is the cathode 23 and spaced therefrom the anode 24. Surrounding the electrodes is the cylindrical, radiation surface 25 which has ample area to dissipate heat losses without the need of fins. Both cylindrical ends, excepting the furnace tube opening at one end, are provided with three layers of reflective insulation 27, 28 and 29 with void gaps which serve to limit heat loss from the generator furnace for increased efficiency of operation. Disposed within the region which separates the cathode and anode cells are the cesium vapor and the additive gases 31. According to our present knowledge the gases released by the aluminum oxide may be replaced by oxygen which also serves to reduce effectively the effective ionizing potential of the cesium vapor. It is thus seen that if the front of the device is arranged so that the opening of the furnace tube is at the focal point of the collector, the temperature inside the tube can be raised to the point where the two electrodes are brought to operating temperature. Electrical power is efficiently delivered to the output circuit which is connected to cathode lead 32 and anode lead 33 and will continue after the sun's rays are removed from the collector because of the presence of the beryllium metal which acts as a heat storage reservoir.

Various modifications of the invention may be effected by persons skilled in the art without departing from the scope and principle of invention as defined in the appended claims.

What is claimed is:

1. A thermionic converter having a pair of electrodes, one of said electrodes being a high electron emission density cathode, means for heating said cathode, the composition of said cathode being such that the work function thereof is substantially the same over its entire surface area, the other electrode of said pair in said converter being formed of a material having a lower work function than the material of said cathode, a positively ionizable gas in the interelectrode space serving during operation to neutralize space charge effect, said gas becoming ionized when the electrons emitted by the cathode collide with the electrically neutral particles of said gas whereby the energy of ionization is obtained principally from the electron stream.

2. A thermionic converter having only two electrodes, namely, an anode electrode and an electron emitting cathode electrode, a heater for said cathode electrode, a

positively ionizable gas in the interelectrode space the positive ions of which serve to neutralize space charge effect in said converter, the composition of each of said electrodes including said cathode electrode being such that their work functions are lower than the ionization potential of said gas whereby the energy of ionization is obtained principally from the electron stream.

3. A thermionic converter as defined in claim 1 in which an additive gas is disposed in the interelectrode space, said additive gas being adapted to depress the ionization potential or electron affinity of the ionizable gas for facilitating its ionization.

4. A thermionic converter as defined in claim 1 in which there is provided an aluminum oxide capsule and means for heating said capsule independently of the means for heating said cathode.

5. A thermionic converter as defined in claim 3 in which said additive gas is oxygen.

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MILTON O. HIRSHFIELD, *Primary Examiner.*