April 28, 1970 J. PSAROUTHAKIS 3,509,385

THERMIONIC CONVERTERS

Filed Jan. 5, 1965 2 Sheets-Sheet 1

FIG. 1

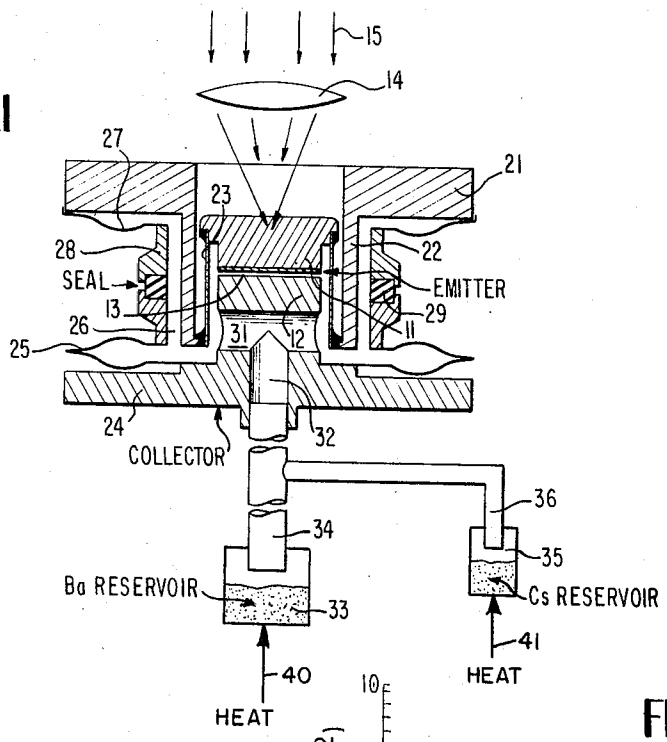

FIG. 2

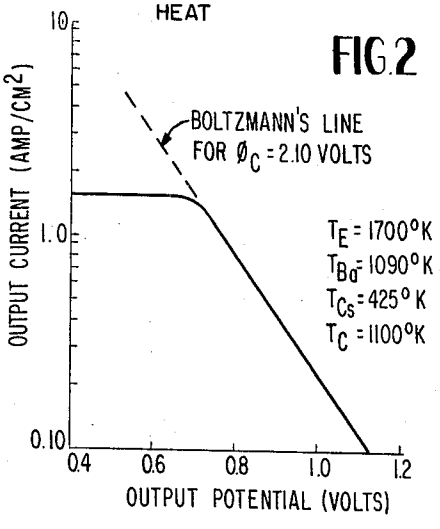

FIG. 3

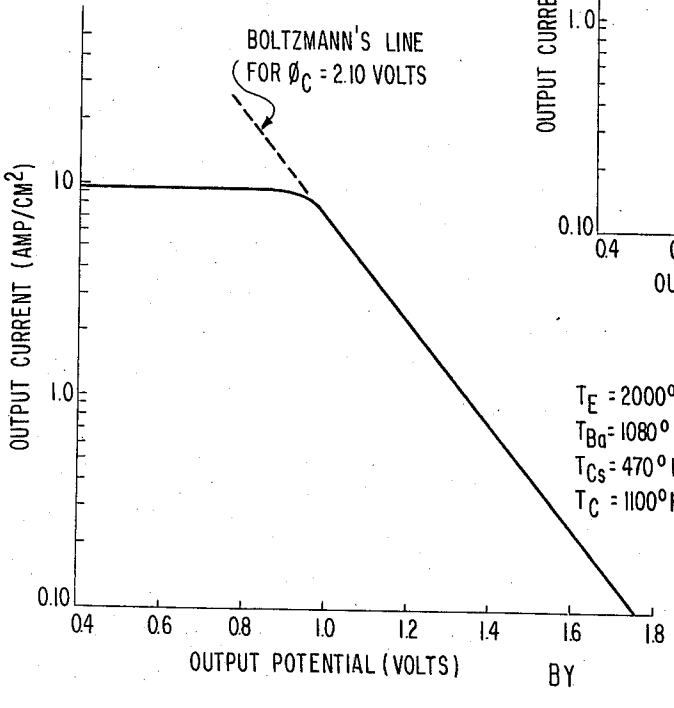

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FIG. 4

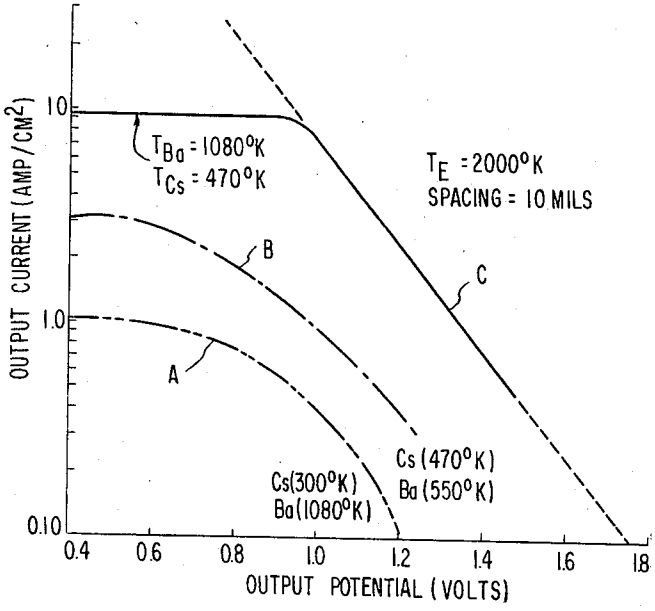


FIG. 5

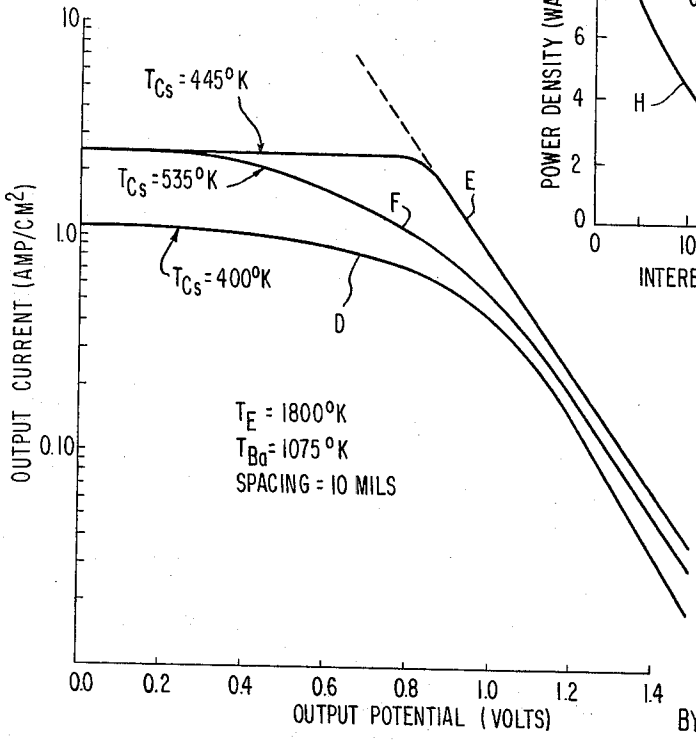
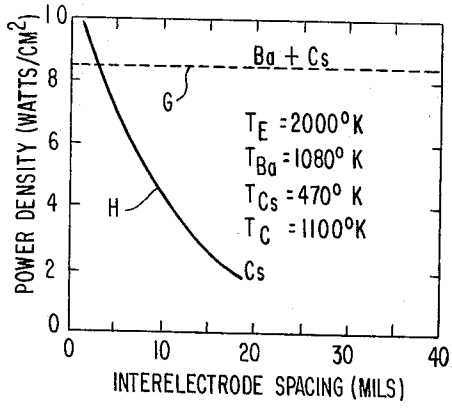


FIG. 6



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THERMIONIC CONVERTERS

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U.S. Cl. 310—4 6 Claims

This invention relates to devices for the interconversion of thermal and electrical energy and more particularly to thermionic energy converters employing ionizable gases therein.

The term "thermionic energy converter" is to be understood to apply to that type of device having an emitter or cathode which, when heated, emits electrons which travel across an interelectrode space to a collector or anode to transport a current. Such devices, it is known, are useful for purposes such as the conversion of thermal energy into electrical energy and, conversely, for the conversion of electrical energy into thermal energy. In operation, the evaporation of electrons from the emitter surface tends to develop a negative space charge which surrounds the emitter surfaces and acts as a barrier inhibiting the flow of current in the device. The suppression of the electron space charge barrier in practical thermionic converters is an absolute necessity for the realization of acceptable performance levels in terms of higher power densities and greater efficiencies.

Another factor to be dealt with in raising the performance of thermionic diodes to acceptable levels is the reduction of the work function of the emitter surface. The higher the emitter work function, the more difficult it is for electrons to escape the emitter surface to support a current in the energy conversion device.

The use of alkali metal vapors in thermionic energy converters has been proposed for two principal purposes. In operation the alkali metal, usually cesium, coats the surface of the emitter which is generally constructed of a refractory metal. Because of its electronic properties the alkali metal coating effectively provides a low emitter work function. In addition, the vapors of alkali metal in contacting the heated emitter surface, become ionized and introduce positive electrons within the interelectrode space which tend to neutralize the negative space charge barrier.

It has been observed that thermionic energy conversion devices employing a single ionizable vapor such as cesium experience important limitations on the power density which they can support an the conversion efficiency of which they are capable. The limitations which have been observed in such devices are believed to be caused by transport effects on the electrons as they migrate from one electrode to the other through a very dense cesium vapor. A high vapor density of the cesium vapor within the interelectrode space has been necessary in order to satisfy the dual performance requirements of simultaneously reducing the electrode work function and of generating sufficient ions within their interelectrode space to neutralize the space charge barrier. The limitations imposed by this dual function of cesium or of other metals which are sometimes substituted for cesium, are particularly severe when the emitter is made of a refractory metal.

One of the transport processes which has inhibited the performance of such devices in the past is that of electron scattering. Electron scattering effects are reduced as the number of electron collisions with cesium atoms are reduced. In general, the parameter that determines the degree of electron collision is the ratio between the mean free path of the electrons and the interelectrode spacing. It has been observed that electron scattering becomes negligible when this ratio is larger than unity. Therefore, at high vapor densities, when the mean free path of the electrons is comparatively small, a collisionless operation requires impractically small electrode spacings which are difficult to produce in the manufacture of the device and even more difficult to maintain during operation of the device. Furthermore, if the rate of ion generation at the emitter surface is not sufficient for space charge neutralization purposes, aditional ions must be generated by inelastic collisions within the interelectrode space between highly energetic electrons and the atoms of the ionizable vapor therein.

In cesium vapor-filled converters, inelastic collisions of this nature cause potential losses within the device of at least one half volt if the distance between the electrodes is comparable to the mean free path of the electrodes. For larger interelectrode spacings, the loss is even greater.

To prevent this potential loss within the device by inelastic collisions between electrons and atoms of the ionizable vapor, the ratio of the mean free path of the electrons to the interelectrode spacing can be improved by employing low cesium vapor pressures. However, for interelectrode spacings larger than .005 inch, the reduced cesium pressure required to optimize that ratio is so low that it is inadequate to coat the heated emitter to reduce the work function of the emitter surface to a level which will provide copious electron emission.

In a cesium-filled thermionic converter, the neutralization pressure can be defined as the cesium pressure which provides sufficient surface ions for neutral emission. The neutralization pressure at any given power density puts an upper limit on the size of the interelectrode spacing which may be employed if the ratio of the mean free path of electrons to interelectrode spacing is to be kept equal to or greater than 1.

In the absence of transport effects in a vapor-filled thermionic converter wherein the vapor pressure of the vapor is equal to the neutralization pressure, a typical voltage current characteristic when plotted on semi-log form consists essentially of two straight lines; a horizontal line which corresponds to the saturation current of the emitter, and an oblique line corresponding to the Boltzmann line. Thermionic operation without transport effects has been termed the IdealMode. To date, however, such operation has not been achievable at practical output power densities primarily because of the high cesium pressure necessary for the operation of converters using cesium vapor alone. In such converters neutral emission cannot be attained at practical emitter temperatures because the vapor pressure needed for the adsorption system of cesium on typical emitter materials is substantially greater than the neutralization pressure necessary to generate, by surface ionization, the exact number of ions for space charge neutralization.

When the vapor pressure falls below the neutralization pressure for a given emitter work function, then an excess of electrons is emitted as compared to ions generated. To neutralize the resulting net space charge, additional ions must be generated by other means. One mechanism by which this has been accomplished with prior devices is by the production of ions through electron collisions with neutral or excited atoms in the space between the electrodes. When an electron is involved in inelastic collisions such as these, it loses a certain portion of its energy. This is a transport loss which is exhibited as an internal potential drop within the thermionic device.

The upper limit of attainable performance characteristics in thermionic energy converters is fundamentally fixed by thermodynamic limitations and by limitations imposed by emission processes which are essential to the operation of the converter. Limitations on the perform-

ance of the thermionic energy converters caused by transport processes such as space charge barriers, electron scattering, and volume ionization of interelectrode gases need not be considered essential and should be eliminated or drastically reduced if the theoretically possible Ideal Mode of operation is to be realized.

This invention has as one of its principal objects to provide novel thermionic conversion devices capable of functioning at improved conversion efficiencies and at increased power densities with substantially reduced transport losses.

A further object of the invention is the provision of improved thermionic devices permitting the use of relatively large interelectrode spacings and having electrical characteristics which are substantially independent of variations in the interelectrode spacing.

Another object of this invention is the provision of thermionic energy converters having an emission-limited performance characteristic substantially free of transport limitations.

A still further object of this invention is the provision of new and improved thermionic conversion devices in which the emitter work function is modified substantially independently of the generation of space-charge neutralizing ions.

A specific object of the invention is the provision of thermionic conversion devices employing within the interelectrode space a mixture of at least two vapors at selected vapor pressures, one of which vapors functions to modify the emitter work function and the other of which functions to generate the positive ions employed for reduction of the space charge.

A still more specific object of the invention is the provision of thermionic conversion devices employing alkali metal vapors at compartively low neutralizing pressures to generate positive ions within the interelectrode space and alkaline earth metal vapors functioning to reduce the emitter function.

In carrying out the invention in one of its embodiments, a thermionic diode is provided in which performance substantially independent of interelectrode spacing is obtained through the use of a mixture of barium and cesium vapors in the interelectrode space at compartively low vapor pressures. The barium vapors are employed to modify the emitter work function and the cesium vapors to provide positive ions by surface ionization. Both the efficiencies and output power densities are considerably higher when both vapors are present than when either vapor is used alone. The efficiency of a mixed-vapor thermionic converter of this type tends to be about twice that of a comparable device employing only cesium vapors. Thermionic converters making use of such a mixture of interelectrode vapors function efficiently with comparatively large interelectrode spacings and are therefore distinguished by high reliability and long life without, however, sacrificing performance characteristics. The high electrode spacings permissible in the practice of this invention are especially desirable from a manufacturing standpoint. Another major advantage of an arrangement of this type is that power density and efficiency in the device is only weakly affected by substantial changes in vapor pressures, whereas in the typical cesium filled converter performance is critically dependent on precise control of vapor pressure.

Although the scope of the invention is not to be limited except by the claims appended hereto, further details of the invention as well as additional objects and advantages will be more clearly understood with reference to the following complete description taken together with the accompanying drawings wherein:

FIGURE 1 is a cross-sectional view of an illustrative thermionic diode constructed in accordance with the principles of this invention;

FIGURE 2 is a potential-current characteristic plot of the performance of the diode shown in FIGURE 1 under selected parameters;

FIGURE 3 is another potential-current characteristic plot of the diode shown in FIGURE 1 under different parameters;

FIGURE 4 is a series of potential current plots comparing the operation of a diode constructed and operating in accordance with this invention with the operation of other diodes;

FIGURE 5 is a family of characteristic curves illustrating the effect of variations in vapor pressure of certain vapors in a device constructed in accordance with this invention; and

FIGURE 6 is a graphical comparison of the effects of variations in interelectrode spacing contrasting the performance of a cesium-filled thermionic diode with that of a diode constructed in accordance with this invention.

In FIGURE 1 there is shown in cross-section an illustrative thermionic energy converter constructed in accordance with this invention. The device shown therein includes certain features, of value in testing the device and measuring its performance characteristics, which would not necessarily be incorporated in a production device intended for the generation of commercial electrical power. The external configuration of the device shown in this illustration constitutes an envelope within which is located an emitter electrode **11** having an emission surface facing the collector surface of a collector electrode **12** across an interelectrode space **13**. In operation the emitter **11** is heated to an elevated temperature substantially above that of the collector electrode to generate the emission of electrons which travel across the interelectrode space **13** to the collector electrode **12** to support a current through the device.

The materials of which the emitter and collector are formed are optional, although they should be capable of withstanding high temperatures during operation. Since the temperature of the emitter may extend from about 1200° K. to 2000° K. and even higher, refractory metals and refractory metal alloys are generally the materials of choice. Of course, only those materials which are not chemically reactive to vapors introduced into the interior of the device should be considered. With an emitter of tungsten and a collector of molybdenum highly satisfactory results are achievable.

The means for heating the emitter electrode **11** is represented diagrammatically in this illustration by the lens **14** which collects solar energy represented by rays **15** and focuses it on the back surface of the emitter **11**. It will be understood, however, that any heat source capable of raising the temperature of the emitter to operational levels is appropriate, and that the solar heating concept is broadly illustrative of means for heating the emitter electrode.

In the embodiment of the invention illustrated in FIGURE 1, the emitter **11** is mounted in such a way as to minimize thermal conductance between the emitter and the flanged mounting member **21** which supports it. For this purpose, the flanged mounting member **21** includes a tubular support portion **22** extending concentrically around the emitter **11** and terminating some distance below the emitter as represented in this illustration. The emitter **11** is welded to one end of a thin cylindrical shell **23** which is welded at its opposite end to the lower terminus of the tubular support section **22**, constituting a part of the flanged mounting member **21**. Because of the high thermal resistance of the thin cylindrical shell **23**, conductive heat transfers from the emitter are minimized.

The collector in this illustrative embodiment constitutes an integral part of its terminal member **24** which comprises a major mounting flange extending radially around its periphery. In general, the collector terminal is mounted to dissipate much of the heat which it may acquire during operation because of its proximity to the heated emitter, in order to sustain a temperature substantially lower than that of the emitter electrode.

The interelectrode space **13** is sealed off from the atmosphere by envelope components which in this example comprise a flexible bellows **25** welded at one side to the collector electrode terminal member **24**. The opposite side of bellows **25** is welded to a sealing member **26**. A half bellows section **27** is joined by welding to the emitter electrode mounting member **21** and to another sealing member **28**. Between the sealing members **26** and **28**, is positioned an annular insulating seal **29**, preferably of aluminum oxide or a similar ceramic, to which both sealing members **26** and **28** are joined by brazing. The bellows and sealing members thus constitute a part of the total envelope which seals the interior of the thermionic device from the atmosphere. The nonconducting nature of the seal **29** ensures electrical isolation between the emitter and collector electrodes except by emission across the interelectrode space **13**.

In the practice of this invention the interelectrode space **13**, evacuated and outgassed during assembly, is filled during operation with vapors of at least two metals. To introduce these vapors into the inter-electrode space, the collector **12** includes an aperture **31** extending through the sides thereof and a conduit **32** forming a T-joint with the aperture **31** for the introduction of vapors. A first reservoir **33** containing one or more alkaline earth metals is positioned away from the immediate thermal environment of the emitter and collector, but communicates with the conduit **32** by a conduit section **34**. A second reservoir **35** communicates with the conduit **32** by a tubular connecting section **36**. The second reservoir contains one or more alkali metals.

The alkali metal vapor currently preferred for introduction into the interelectrode space is cesium because of its low ionization potential. Barium is preferred as the alkaline earth metal vapor partly because of its low electron collision cross-section. These elements, however, should be understood as representative of their respective classifications. Not only may other alkaline earth metals and alkali metals be substituted in their place, but also there is no reason to believe that mixtures of one or more metals from each classification may not be equally as effective, if not more so.

The reason for introducing two different kinds of vapors into the interelectrode space is that each functions in a manner complementary to the other to reduce transport losses. The alkali metal vapor is employed only for the purpose of generating positive ions by contact ionization to neutralize the negative space charge barrier. The pressure of the alkali metal vapor is therefore maintained at or about the neutralization pressure, that is to say, at that pressure which provides sufficient surface ions at the emitter for neutral emission to take place. This vapor pressure affects the mean free path of the electrons emitted and places an effective upper limit on the size of the interelectrode spacing if, as is desirable, the ratio of the mean free path of the electrons to the interelectrode spacing is to be kept equal to or greater than 1.

It is to be noted that at or near the neutralization pressure, the alkali metal vapor is insufficient to coat the emitter with a layer. Therefore the alkali metal vapor exerts little influence on the thermionic work function of the emitter. Under such circumstances, if no other vapor were present in the interelectrode space, the electron emission from the emitter surface would not be sufficiently copious to support large load currents through the device.

In the embodiment discussed, the alkaline earth metal vapor introduced into the interelectrode space, is also at a comparatively low vapor pressure. However, the vapor pressure necessary to permit barium and other alkaline earth metals to coat the surface of the emitter at operational temperatures, is much less than which would be required for cesium or other alkali metals to perform a similar function. In addition, when alkali metal vapors are present with alkaline earth metal vapors at similar vapor pressures, the latter are preferentially adsorbed on the heated emitter surface. Consequently, the alkaline earth metal vapors create a film on the emitter surface which exerts a dominant influence on the thermionic work function thereof.

It should be mentioned that although other alkaline earth metals may be substituted in place of barium, the substitution of strontium or calcium may even produce improved results, particularly when low collector work functions are considered. The vapors of strontium and calicum have about the same adsorption properties as those of barium, but produce higher vapor pressures for a given reservoir temperature.

Two reservoirs, **33** and **35**, are employed in the embodiment illustrated for the purpose of selectively regulating the vapor pressures of the two types of vapor introduced into the interelectrode space. Since the vapor pressures of these vapors are determined by the temperature of the coldest surface within the device to which the vapors have access, the two reservoirs are separated from the thermal environment of the emitter and collector in order that their temperatures may be regulated independently thereof. The collector should in any event be warmer than either reservoir. The manner in which the temperatures of the two reservoirs is regulated is of course, a matter of choice. In some cases it may be necessary to regulate these temperatures by heating the reservoirs, in others cooling may be necessary. For illustrative purposes, the preferred embodiment of FIGURE 1 diagramatically shows the case wherein the barium reservoir **33** and the cesium reservoir **35** are each separately heated to the desired temperatures by heat inputs illustrated by arrows **40** and **41**, respectively.

It should be pointed out that for any system utilizing two vapors that have distinctly different saturation temperatures for the same vapor pressures, a continuous condensation of the higher temperature vapor into the lower temperature reservoir will take place. The effects of such an operation will include the depletion of one of the reservoirs and the eventual loss of that vapor pressure. Although at first this may appear to be a problem, upon investigation the problem does not appear great, partly because the range of the vapor pressures typically employed is quite small. In fact, the rate of loss is small. For example, after operating a device such as that illustrated in FIGURE 2 for 700 hours, it was found that a condensation of only 0.3 gram of barium had taken place into the cesium reservoir.

The data shown in FIGURE 2 represents the current-potential characteristic of a thermionic diode such as that illustrated above with the temperature of the emitter, T_e, at approximately 1700° K. and the temperature of the collector, T_c, at about 1100° K. In this case the temperature of the barium-filled reservoir, T_{ba}, was maintained at approximately 1090° K. and that of the cesium-filled reservoir, T_{cs}, at 425° K. These reservoir temperatures, of course, determine the vapor pressures of the barium and cesium introduced into the interelectrode space. It is to be noted that the shape of this characteristic curve, which approximates two intersecting lines, approaches that of an Ideal Mode characteristic for a thermionic diode with emission-limited operation and no transport losses. Equally as important if not more so, is the fact that the characteristic illustrated is substantially independent of interelectrode spacing up to and including distances as great as 40 mils as will be seen below.

In FIGURE 3 is shown a similar characteristic curve for the thermionic diode illustrated above operating at a higher emitter temperature of 2000° K. The collector temperature, in this case, is again 1100° K. The temperatures of the barium and cesium reservoirs were maintained at 1080° K. and 470° K. respectively. Once more the nearly ideal form of the characteristic curve is to be noted. It is particularly important to notice that in both characteristic curves shown in FIGURES 2 and 3, the

well defined emission-limited curves were obtained at relatively high current densities. To my knowledge, such data have never been obtained in high density cesium-filled thermionic converters.

In FIGURE 4 are shown three current-potential curves taken at the same emitter temperature in a device constructed substantially as described above. The lowest of these curves A represents the operation of the diode with the cesium reservoir held at a relatively low and ineffective temperature of 300° K. while the barium reservoir was at 1080° K. The middle curve B was obtained with the barium reservoir held at a comparatively low temperature of 550° K. and the cesium reservoir elevated to a temperature of 470° K. The upper or saturated curve C corresponds to that of FIGURE 3, and is obtained when the temperature of the barium reservoir is at the temperature used to produce the characteristic A curve and the cesium reservoir at a temperature used to produce the characteristic curve B. In each case the interelectrode spacing was fixed at 10 mils. These three curves depict very clearly the advantages of combining barium and cesium vapors in a single diode and they illustrate how the combination of vapors exceeds the sum of its parts.

FIGURE 5 shows three current-potential characteristics taken at fixed emitter, collector and barium reservoir temperatures, but at three different cesium reservoir temperatures. Herein can be seen the importance of maintaining the vapor pressure of the cesium at or near its neutralization pressure. At a very low cesium reservoir temperature of 400° K., the cesium ions generated were insufficient for neutralization purposes and the full advantages of the diode were not realized as can be seen by the lower characteristic curve D. At a cesium reservoir temperautre of 445° K., which represented the neutralization pressure, the characteristic curve rose almost to its full theoretical capability as shown by curve E. At cesium reservoir temperatures above the neutralizing value of 445° K., the curve F again deviated from the fundamental characteristic of the device, apparently as a result of the increased transport losses, because of space ionization and electron scattering due to the relatively high cesium vapor pressures.

One of the most important advantages of the invention is illustrated by the graph in FIGURE 6. This graph shows that the output power density of the thermionic diode is substantially independent of interelectrode spacing. It is to be recalled that the device shown in FIGURE 2 is constructed with bellows in the outer envelope to permit the space between the emitter and electrode to be varied in operation, although this would not generally be necessary in a production-model diode. The curves shown in FIGURE 6 were taken from data obtained at different interelectrode spacings. The almost horizontal curve G in the upper portion of the graph represents the operation of a device such as that shown in FIGURE 1 under the parameters specified in connection with the characteristic curve of FIGURE 3. Here it can be seen that the power output of the device remains independent of interelectrode spacing up to the comparatively large space of 40 mils which approaches the mean free electron path. Variations in interelectrode spacing obviously had substantially no effect upon the power output of the device.

The curve H which represents the operation of a cesium-filled converter operating under similar conditions but without barium vapors present in the interelectrode space tells a different story. There it can be seen that the transport effect for a cesium-filled converter exert a dominant influence as the interelectrode spacing is increased in such a way that the power output falls off dramatically.

It can thus be seen that in the practice of this invention by modifying the emitter work function with an alkaline earth metal, and by using a low vapor density alkali metal for ion generation at the emitter surface, a spacing-independent, emission-limited, inherently efficient operation is achieved substantially free of transport effects. In carrying out this invention output power densities of 8.5 watts per square centimeter and fundamental conversion efficiencies of 27% have already been produced, both of which are substantially independent of variations in interelectrode spacing for distances up to and including 40 mils. Data extrapolations suggest strongly that even higher power densities of 15 watts per square centimeter and fundamental conversion efficiencies greater than 30% are achievable.

Although one principal embodiment of the invention has been illustrated and described, it will be apparent to those skilled in the art that many variations and substitutions may be made wthiout departing from the practice of this invention. It is therefore to be understood that the following claims are intended to cover all such variations and substitutions as come within the true spirit and scope of the invention in its broader aspects.

What is claimed is:

1. A thermionic energy conversion device comprising:
an emitter electrode;
a collector electrode separated from said emitter electrode across an interelectrode space;
means for heating said emitter electrode to a temperature substantially above that of said collector during operation of said device;
a first reservoir containing at least one alkali metal communicating with said interelectrode space; and
a second reservoir containing at least one alkaline earth metal communicating with said interelectrode space,
means for controlling the temperatures of said reservoirs to establish within said interelectrode space a mixture of alkali metal and alkaline earth metal vapors at comparatively low vapor pressures, the vapor pressure of said alkali metal vapor being too low to exert a substantial effect on the work function of said emitter electrode at the temperature of operation thereof, the vapor pressure of said alkaline earth metal vapor being sufficiently high to exert a dominant effect on the work function of said emitter electrode.

2. An emission-limited thermionic energy conversion device comprising:
an emitter electrode;
a collector electrode separated from said emitter electrode across an interelectrode space;
means for heating said emitter electrode to a temperature substantially above that of said collector electrode during operation of said device;
a first reservoir containing an alkali metal communicating with said interelectrode space;
a second reservoir containing an alkaline earth metal communicating with said interelectrode space; and
means for selectively controlling the temperatures of said reservoirs to establish within said interelectrode space a mixture of alkali metal and alkaline earth metal vapors at comparatively low vapor pressures, the vapor pressure of said alkali metal vapor being too low to exert a substantial effect on the work function of said emitter electrode at the temperature of operation thereof, the vapor pressure of said alkaline earth metal vapor being sufficiently high to exert a dominant effect on the work function of said emitter electrode.

3. An emission-limited theromionic energy conversion device comprising:
an emitter electrode;
a collector electrode separated from said emitter elecan interelectrode space;
means for heating said emitter electrode to a temperature substantially above that of said collector electrode across an interelectrode space;
a first reservoir containing an alkali metal communicating with said interelectrode space;

a second reservoir containing an alkaline earth metal communicating with said interelectrode space; and

means for selectively controlling the temperatures of said reservoirs to establish within said interelectrode space a mixture of alkali metal and alkaline earth metal vapors at comparatively low vapor pressures, the vapor pressure of said alkali metal vapor being too low to exert a substantial effect on the work function of said emitter electrode at the temperature of operation thereof, the vapor pressure of said alkaline earth metal vapor being sufficiently high to exert a dominant effect on the work function of said emitter electrode, both vapor pressure being insufficient to reduce the mean free path of electrons travelling across said interelectrode space to less than the separation distance between said electrodes.

4. A thermionic energy conversion device comprising:

an emitter electrode;

a collector electrode separated from said emitter electrode across an interelectrode space;

means for heating said emitter electrode to a temperature substantially above that of said collector electrode during operation of said device;

a first reservoir communicating with said interelectrode space and containing an alkaline earth metal at a temperature sufficient to introduce alkaline earth metal vapors into said interelectrode space at a vapor pressure sufficient to coat said emitter electrode with a layer of alkaline earth metal to reduce the work function thereof; and

a second reservoir communicating with said interelectrode space and containing an alkali metal at a temperature lower than that of said collector electrode but sufficient to introduce alkali metal vapors into said interelectrode space at substantially the space charge neutralization pressure determined by the temperature and work function of the emitter surface, the separation distance between said electrodes being less than the length of the mean free path of electrons thermionically emitted from said emitter electrode.

5. A thermionic energy conversion device comprising:

an emitter electrode;

a collector electrode separated from said emitter electrode across an interelectrode space;

means for heating said emitter electrode to a temperature substantially above that of said collector electrode during operation of said device;

a first reservoir containing cesium communicating with said interelectrode space; and

a second reservoir containing barium communicating with said interelectrode space,

means for regulating the temperatures of said reservoirs to establish within said interelectrode space a mixture of cesium and barium vapors at comparatively low vapor pressures, the vapor pressure of said cesium vapor being too low to exert a substantial effect on the work function of said emitter electrode at the temperature of operation thereof, the vapor pressure of said barium vapor being sufficiently high to exert a dominant effect on the work function of said emitter electrode.

6. A thermionic energy conversion device comprising:

an emitter electrode;

a collector electrode separated from said emitter electrode across an interelectrode space;

means for heating said emitter electrode to a temperature substantially above that of said collector electrode during operation of said device;

a first reservoir communicating with said interelectrode space and containing barium at a temperature sufficient to introduce barium vapors into said interelectrode space at a vapor pressure sufficient to coat said emitter electrode with a layer of barium to reduce the work function thereof; and

a second reservoir communicating with said interelectrode space and containing cesium at a temperature lower than that of said collector electrode but sufficient to introduce cesium vapors into said interelectrode space at substantially the lowest neutralization pressure required to neutralize space charge effects around said emitter electrode, said neutralization pressure being determined by the temperature and character of the emitter surface, the separation distance between said electrodes being shorter than the mean free path of electrons thermionically emitted from said emitter electrode.

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