Oct. 5, 1965 L. PODOLSKY 3,210,575

THERMOELECTRON ENGINE HAVING COMPOSITE EMITTER

Filed March 7, 1961

3 Sheets-Sheet 1

Fig. 1

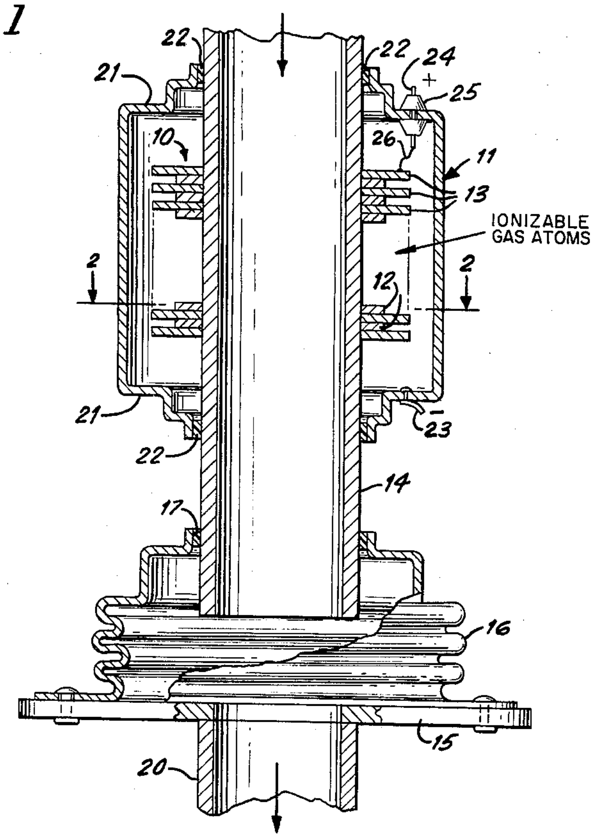


Fig. 8

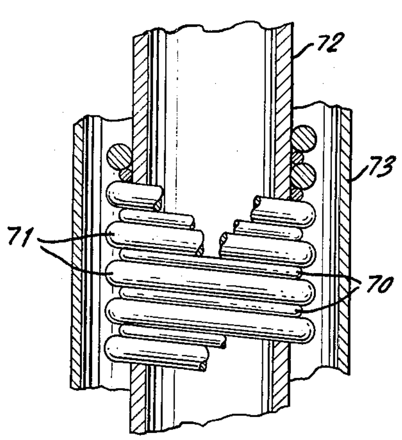
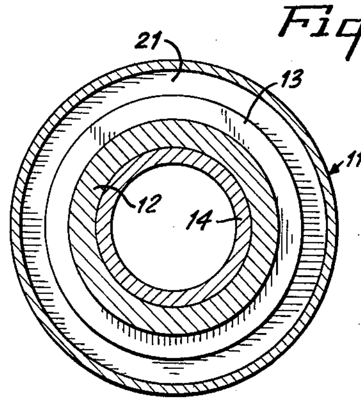


Fig. 2



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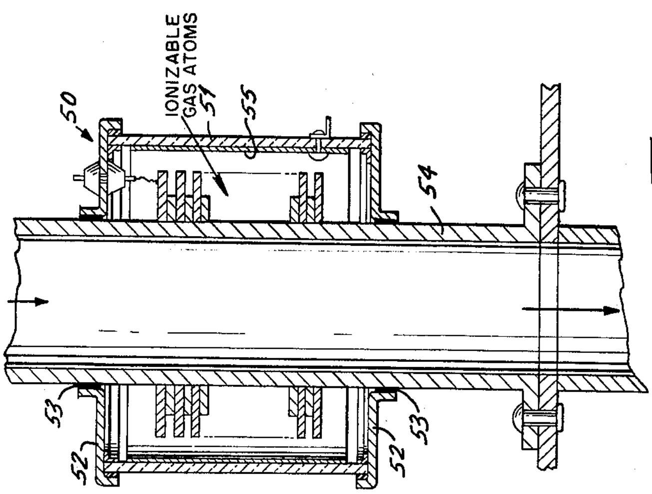

Fig. 5

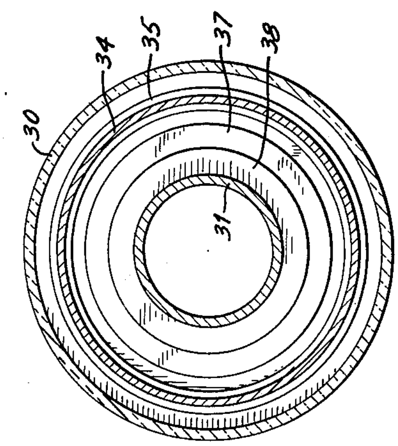

Fig. 4

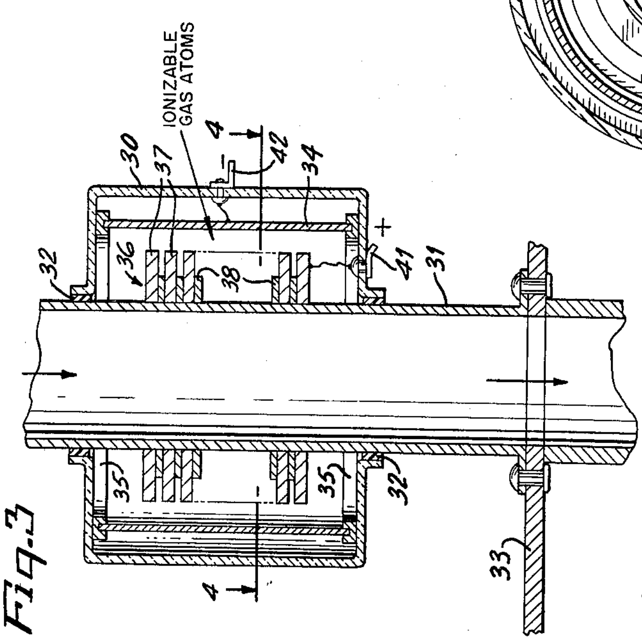

Fig. 3

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Fig. 6

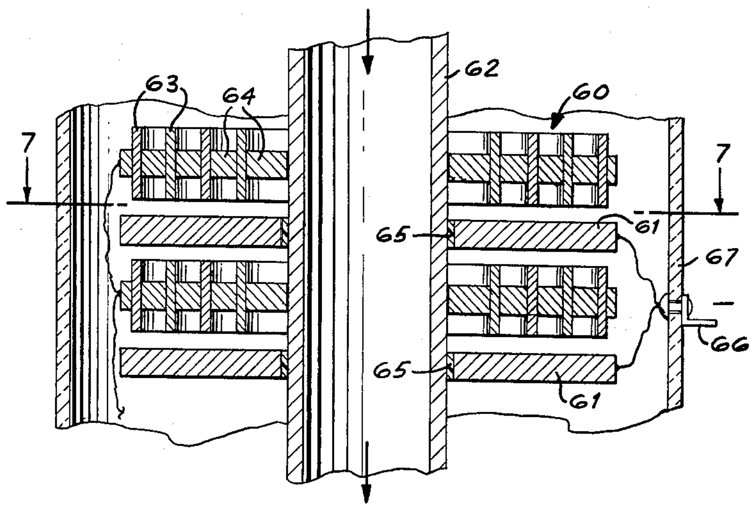
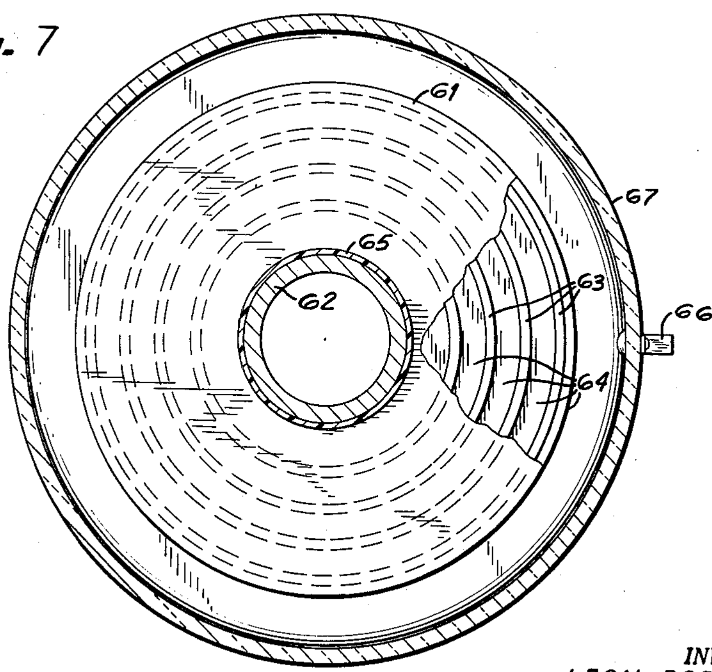


Fig. 7



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THERMOELECTRON ENGINE HAVING COMPOSITE EMITTER

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15 Claims. (Cl. 310—4)

This invention relates generally to thermionic converters, or so-called thermoelectron engines, and has particular reference to an emitter of novel character for such engines or converters.

Thermoelectron engines, as is well known, are devices for directly converting heat into electricity without the use of moving mechanical parts. They comprise, generally, an emitter or "hot" plate heated by any convenient source, and a collector or "cold" plate spaced from the emitter. The emitter is heated sufficiently to cause electrons to leave its surface and migrate toward the collector. There, electrons give up their negative charges to the collector, thus engendering an output voltage between the emitter and the collector.

In order to reach the collector, the electrons must work against the potential difference between the emitter and collector and hence must leave the emitter with at least enough kinetic energy to overcome this potential difference. Many of the emitted electrons do not have the requisite kinetic energy to reach the collector, and these electrons create an additional retarding potential, commonly called a space charge, in the region between the emitter and the collector. The electrons which reach the collector must initially, therefore, have enough kinetic energy to overcome the cumulative effect of the potential difference between the plates, and the space charge.

Unless the space charge is maintained at a very low value, only extremely fast moving electrons, representing a small percentage of all emitted electrons, will get through to the collector, and no appreciable power will be obtained from the engine. A major problem to be overcome before thermoelectron engines can become thoroughly practical for commercial use is the minimization of the space charge to insure that as large a proportion as possible of the emitted electrons travel the entire route from emitter to collector. One approach taken toward solution of this problem has been the introduction into the region between the plates of a gas, such as cesium gas, comprising positive ions which serve to "neutralize" the electrons creating the space charge. In order to maintain the cesium in gaseous form enough heat must be supplied between the plates to ionize it. A convenient source of this heat is the emitter itself, but unless the work function of the emitter material (i.e., the amount of energy required to free electrons from the surface of the material) is higher than the ionization energy of the cesium (3.89 electron-volts), a large proportion of the cesium atoms striking the emitter will not be ionized. The difficulty which presents itself at this point is that if the surface of the emitter is provided with a uniformly high work function, to insure ionization of the cesium, inordinately high temperatures are required to maintain current density of emission at practical values.

In view of this difficulty, it has been suggested that an emitter with a composite surface be used, the surface having areas of relatively low work function to provide abundant electron emission, and other areas of relatively high work function to maintain the presence of positive ions in the region between the plates. A "patchy" tungsten surface having different areas of high and low work function respectively has been proposed for this type of emitter. However, the effectiveness of such an emitter in reducing the space charge has been questioned since the ions produced at the areas of high work function do not readily move into the regions adjacent to the low

work function areas where the space charge predominates. This is because the high work function areas are slightly more negative than the low work function areas, which have lost electrons, and sence attract or trap the positive ions preventing them from moving into the low work function areas. It has been suggested to electrically insulate and bias the high and low work function portions in order to prevent formation of ion traps, but such an arrangement would require an additional power input and further lower the efficiency of the engine.

It is an object of the present invention to provide a composite emitter capable of overcoming some of the problems encountered heretofore. In accordance with one feature of the invention, the emitter is formed of a series of alternately arranged high and low work function layers, the high work function layers being spaced closer to the collector than the low work function layers. In consequence of this type of construction, the high work function portions of the emitter extend past the low work function portions to the point where a space charge would ordinarily tend to build up by electron emission from the low work function portions. As a result, positive ions for neutralizing the space charge are produced precisely at the point where they can be most effective, viz., in the region at which the space charge would ordinarily form.

It should be noted furthermore, that since the high and low work function portions of the emitter are at about the same potential, the electrons emitted from the low work function portions lose little or no kinetic energy until they move beyond the high work function portions. At this point, those electrons with enough kinetic energy to reach the collector do so, whereas the slower moving electrons which would ordinarily create a space charge are neutralized by the cesium ions.

It is a further object of the present invention to provide a composite emitter of such construction that the effective areas of the high and low work function portions can be accurately controlled in predetermined manner. This is accomplished by proper choice of the thickness of the layers and the dimensions of the layers in the direction of the collector.

It is another object of the invention to provide a thermoelectron engine which is thoroughly practical from an engineering standpoint. Heretofore, in engines capable of producing useful amounts of power, the spacing between emitter and collector has been about .001 centimeter. As a practical matter, it is impossible to maintain such spacing at operating temperatures of about 2,000° F. The present engine can produce comparable amounts of power with an emitter-collector spacing of .1 inch, which is an entirely practical dimension for an engine operating at 2,000° F.

It is a still further object of the invention to provide a composite emitter capable of effectively neutralizing the space charge without requiring any electrical biasing of the high and low work function portions of the emitter.

Other objects and advantages of the invention will be apparent from the following description in which reference is made to the accompanying drawings.

In the drawings:

FIG. 1 is a vertical cross-sectional view of an illustrative thermoelectron engine constructed in accordance with the present invention;

FIG. 2 is a horizontal cross-sectional view taken on line 2—2 of FIG. 1;

FIG. 3 is a view similar to FIG. 1 of an alternative thermoelectron engine;

FIG. 4 is a horizontal cross-sectional view taken on line 4—4 of FIG. 3;

FIGS. 5 and 6 are views similar to FIG. 1 showing other alternative thermoelectron engines;

FIG. 7 is a horizontal cross-sectional view taken on line 7—7 of FIG. 6; and

FIG. 8 is a fragmentary elevational view, partially in section, of another alternative thermoelectron engine.

It should be mentioned at the outset that, for the sake of clarity, the elements of the thermoelectron engines shown in the drawings are not necessarily in correct proportion.

In FIGS. 1 and 2, the thermoelectron engine shown comprises, generally, an emitter **10** and a collector **11**. The emitter consists of a series or stack of annular rings or disks **12** and **13**, the rings **12** being of smaller diameter than the rings **13**. The rings **12** and **13** are alternately arranged and are in electrical contact with one another. The rings **12** have a relatively low work function, and may be fabricated for example of nickel, tungsten, or zirconium. The rings **13** have a relatively high work function, and may be fabricated for example of tantalum. Alternatively, the rings **12** and **13** may be fabricated of the same metal in which case the surfaces of the low work function rings **12** might be treated with a metallic oxide, such as thorium or barium oxide.

The rings **12** and **13** are mounted on a cylindrical tube **14** in heat conducting relation with it. The tube **14** may be formed for example of an aluminum oxide ceramic, which is an electrical insulator but a good conductor of heat. Obviously, however, any heat conducting material may be used to form the tube. The tube **14** is intended to accommodate a heating medium for heating the emitter **10**. The medium may be for example a hot gas flowing through the tube, the gas being supplied from any suitable source (not shown); or the heat may be supplied by other means, e.g., by a nuclear energy source located or effective within the tube itself.

Inasmuch as aluminum oxide ceramic has a high thermal coefficient of expansion and is relatively weak and sensitive to shock, the lower end of the tube **14** may be advantageously secured to a mounting plate **15** by means of an expandable bellows **16**. A metal to ceramic seal **17** is shown for fastening the bellows to the tube. Below the mounting plate **15**, there is a connection pipe **20** for the gaseous heating medium, if such a heating medium is used.

In the region between the emitter **10** and the collector **11** is an evacuated space containing positive ions. An ionizable substance preferred for this purpose is cesium since it has a relatively low ionization energy.

In the embodiment shown in FIGS. 1 and 2, the metallic collector **11** is formed with upper and lower walls **21** fastened to the tube **14** in gas-tight relation by the metal-to-ceramic seals **22**. The collector **11** thereby serves as a gas-tight housing for the emitter and the cesium gas. Mounted in the lower wall **21** of the collector is a terminal **23**, which is the negative terminal when the thermoelectron engine is in operation. Mounted in the upper wall is a terminal **24**, insulated from the collector by a bushing **25**. The terminal **24** is connected to the emitter by a wire **26** and serves as the positive terminal of the engine.

The actual dimensions of the elements shown in the drawings will, of course, vary with the output requirements of the engine. However, a set of dimensions will now be given by way of example. The tube **14** may have an internal diameter of about one inch and an external diameter of about 1¼ inches; the rings **12** may have an outside diameter of 1.45 inches, and the rings **13** an outside diameter of 1.65 inches; the inside diameter of the collector may be 1.85 inches. It will be seen, therefore, that the rings **13** are spaced .1 inch from the collector, and the rings **12** .2 inch from the collector. In previous thermoelectron engines, the collector-emitter spacing had to be as close as .001 centimeter in order to produce useful amounts of power at all. An engine having approximately these dimensions, with an emitter about 1 inch long (about 20 rings) can develop a current of several hundred amperes at about 3 volts.

In operation, the heating medium in the tube **14** which may be at a temperature of about 2,000° F., heats the emitter **10** to a degree which is enough to drive electrons from the low work function rings **12**. Since the rings **13** have a higher work function than the rings **12** and the outer extremities of the rings **13** are cooler than the rings **12**, there is little or no electron emission from the rings **13**. The rings **13** are, however, hot enough to cause melting and evaporation, and hence ionization, of any cesium atoms which come into contact with them. These rings, therefore, serve to maintain the cesium in ionized condition.

When electrons are emitted from one of the rings **12**, they travel between the rings **13** directly above and below the emitting ring and through a field created by the rings **13**. Since the field is at about the same potential as the ring **12**, the electrons lose little or no kinetic energy until they reach the outer edges of the rings **13**. At this point, there is an atmosphere of positive ions comprising the cesium gas. Those electrons having sufficient kinetic energy to reach the collector against the force of the potential difference between the collector and emitter are not affected by the positive ions. However, the slower moving electrons, having insufficient kinetic energy to reach the collector, and which would ordinarily create a space charge, are in general neutralized or cancelled by the cesium ions. The electrons which reach the collector **11** deposit a negative charge on it which is readable as an output voltage between the terminals **23** and **24**.

The thermoelectron engine of FIGS. 3 and 4 is similar to that of FIGS. 1 and 2 except that a housing **30** of non-conductive material, such as glass or ceramic, is employed. The housing is mounted on a metal tube **31**, in gas-tight relation therewith, by ceramic-to-metal seals **32**. Since a metal tube is stronger and more shock-resistant than the ceramic tube **14** of FIG. 1, no bellows is required, and the tube **31** can be fastened directly to a mounting place **33**. Within the housing **30** is a cylindrical metallic collector **34** held by opposed circular channel members **35** fastened to the inner faces of the upper and lower walls of the housing.

Mounted on the tube **31** within the collector **34** is an emitter **36**, comprising a stack of annular rings **37** and **38**, the rings **37** having a relatively high work function, and the rings **38** having a relatively low work function. Mounted in the housing **30** are two terminals **41** and **42**; the positive terminal **41** being electrically connected to the emitter **36**, and the negative terminal **42** being electrically connected to the collector **34**. The operation of the thermoelectron engine shown in FIGS. 3 and 4 is, of course, substantially as described above with reference to FIGS. 1 and 2.

The thermoelectron engine shown in FIG. 5 is almost identical to the engine of FIGS. 3 and 4. However, the housing **50** comprises a cylindrical member **21** of non-conductive material, held in place by a pair of flanges **52**, which are preferably metal so that they can be welded at **53** to the metallic tube **54**. The inner surface of the member **51** is provided with a metallized layer **55** which serves as the collector. In all other respects, the engine is identical in construction and operation to the engines previously described.

In the thermoelectron engine of FIGS. 6 and 7, the emitter is of different construction and the emitter and collector have a different orientation. Emitter plates **60** and collector plates **61** are arranged in alternate spaced relation along a metallic tube **62**. Each emitter plate comprises a series of annular rings **63** and **64** of successively greater diameter, concentrically arranged. The rings are mounted in heat-conducting relation on the tube **62**, and are alternately of relatively high and low work function. Thus the rings **63** have a high work function, and the rings **64** have a low work function. Furthermore, the high work function rings **63** have a greater dimension in the direction of the longitudinal axis of the tube than the low work function rings **64**.

The metallic collector plates **61**, while being mounted on the tube **62**, are electrically and thermally insulated from the tube by insulators **65**. All the collector plates **61** are electrically connected to a terminal **66** in the housing **67**, and all the emitter plates are electrically connected to another terminal (not shown). It may be seen that despite the different arrangement, the relative relation between any adjacent emitter and collector plates is the same as the relation between the emitters and collectors shown in FIGS. 1–5, i.e. the high work function rings are closer to the collector than the low work function rings. The atmosphere around the plates **60** and **61** is filled with cesium ions, and the housing **67** is mounted by means of gas-tight connections to the tube **62**.

Finally, FIG. 8 shows another type of emitter constructed in accordance with the present invention. This emitter comprises two elongated wires, **70** and **71**, one of relatively low work function and smaller in diameter, and the other of relatively high work function and larger in diameter. The two wires are wound as a dual helix around a metallic tube **72**, the turns along the tube being alternately of high and low work function. The high work function turns formed by the wire **71** are, because of their larger diameter, closer to the collector **73** than the low work function turns formed by the wire **70**. Hence, the operation of an engine constructed as shown in FIG. 8 is exactly the same as the operation of the other engines described above.

It may be seen, therefore, that the present invention provides a composite emitter of unique construction capable of minimizing the space charge, ordinarily found in the region between the emitter and collector of thermoelectron engines, to an extent not heretofore achieved, without the use of any biasing potential or impractical extremely close spacing of elements. The efficiency of an engine incorporating an emitter constructed in accordance with the present invention is therefore increased greatly over the efficiency of engines heretofore known.

The invention has been shown and described in preferred form only and by way of example and many variations and modifications may be made therein and in its mode of operation which will still be comprised within the spirit of the invention. It is understood, therefore, that the invention is not limited in any way by the disclosure, except insofar as such limitations are found in the appended claims.

What is claimed is:

1. A thermoelectron engine comprising a collector, an emitter spaced from said collector, said emitter being at a lower electrical potential than said collector and having an emitting portion and an ionizing portion, said emitting and ionizing portions touching each other and being in electrical contact, a gas comprising positive ions filling the region between said collector and said emitter, and means for heating said emitter to cause electrons to be expelled from the surface of said emitting portion toward said collector, said ionizing portion being nearer to said collector than said emitting portion and serving to heat said gas to maintain it in gaseous state and thereby sustain the presence of positive ions for neutralizing the space charge between said emitter and collector.

2. A thermoelectron engine according to claim **1** wherein said emitting portion has a relatively low work function and said ionizing portion has a relatively high work function.

3. A thermoelectron engine according to claim **1**, including a gas-tight housing for said emitter and gas.

4. A thermoelectron engine according to claim **3** wherein said housing is formed by said collector.

5. A thermoelectron engine according to claim **3** wherein said housing encloses the collector and is composed of non-conductive material.

6. A thermoelectron engine according to claim **3** wherein said housing is composed of non-conductive material and said collector is formed by a metallized layer on the inner surface of said housing.

7. A thermoelectron engine comprising a collector, an emitter spaced from said collector and at a lower electrical potential than said collector, said emitter including adjacent touching portions in electrical contact having different dimensions in the direction of the spacing between said collector and emitter whereby certain of said portions are closer to said collector than others, a gas comprising positive ions filling the region between said anode and emitter, and means for heating said emitter to cause electrons to be expelled from the surfaces of said portions farther from said collector and to cause said portions closer to said collector to heat said gas to sustain the presence of positive ions.

8. A thermoelectron engine according to claim **7** wherein said portions of said emitter having different dimensions are alternately arranged in stacked relationship.

9. A thermoelectron engine according to claim **7** wherein said portions farther from said collector have a relatively low work function and said portions closer to said collector have a relatively high work function.

10. A thermoelectron engine according to claim **7** wherein said emitter comprises a plurality of annular rings arranged in stacked relationship, said rings being alternately of relatively high and low work function, said high work function rings being of larger diameter than said low work function rings.

11. A thermoelectron engine according to claim **10** wherein the internal margins of said rings surround a generally cylindrical region for accommodating said heating means.

12. A thermoelectron engine according to claim **7** wherein said emitter comprises a plurality of annular rings of successively greater diameter, said rings being arranged in concentric relationship and said rings being alternately of relatively high and relatively low work function, said high work function rings having a greater dimension along the longitudinal axes of said rings than said low work function rings.

13. A thermoelectron engine according to claim **12** including a heat-conducting tube for accommodating said heating means said tube passing through the innermost ring of said emitter and said emitter being mounted on said tube in electrical contact therewith, and wherein said collector is an annular disk mounted on said tube and spaced along said tube from said emitter, said collector being insulated from said tube.

14. An emitter according to claim **10** wherein said alternate rings differ in thickness.

15. An emitter according to claim **7** wherein said emitter comprises a pair of adjacent wires wound in a dual helix, said wires differing in diameter, the larger diameter wire being of relatively high work function and the small diameter wire being of relatively low work function.

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