

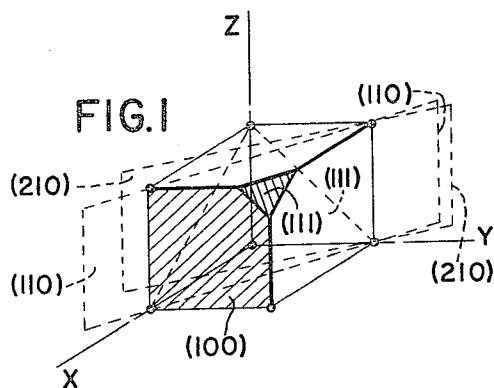
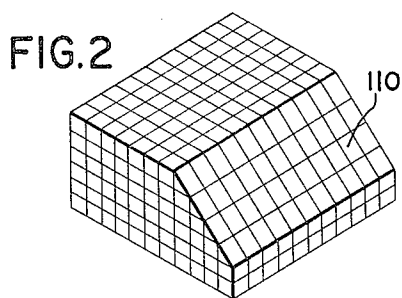
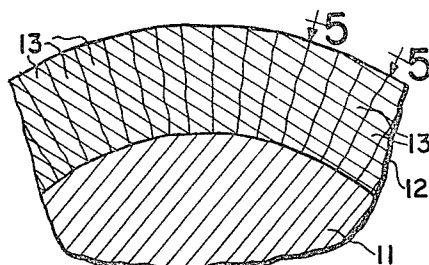
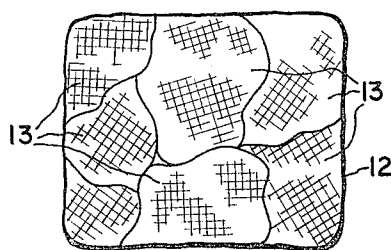
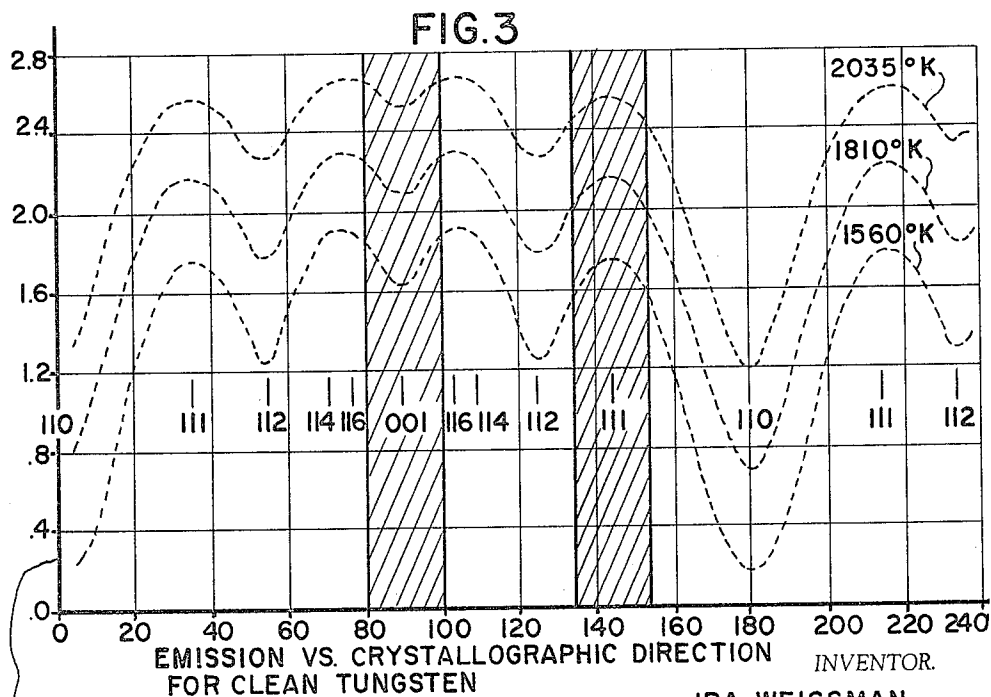
Nov. 8, 1966

I. WEISSMAN
GRAIN-ORIENTED THERMIONIC EMITTER FOR
ELECTRON DISCHARGE DEVICES

3,284,657

Filed June 3, 1963

4 Sheets-Sheet 1



$\text{LOG}_{10} I_v + \begin{cases} 9 \text{ FOR } 2035^\circ\text{K} \\ 10 \text{ FOR } 1810^\circ\text{K} \\ 11.6 \text{ FOR } 1560^\circ\text{K} \end{cases} (I_v \text{ IN AMP})$

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ATTORNEY

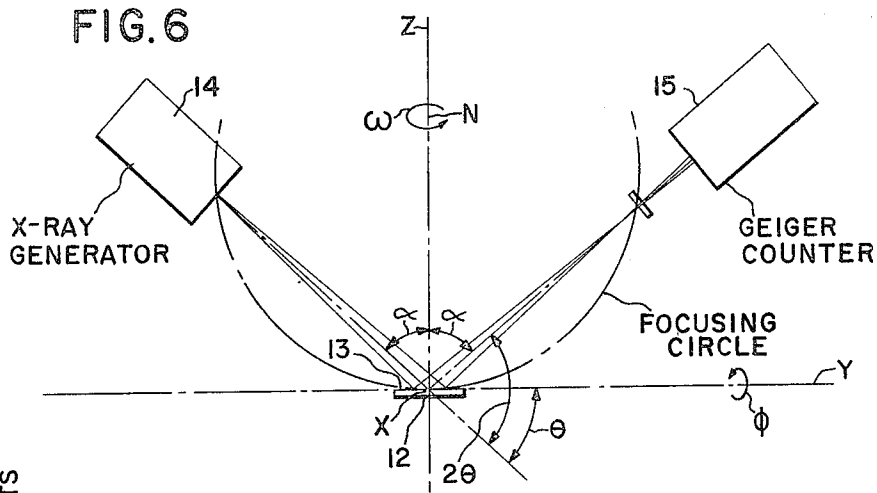
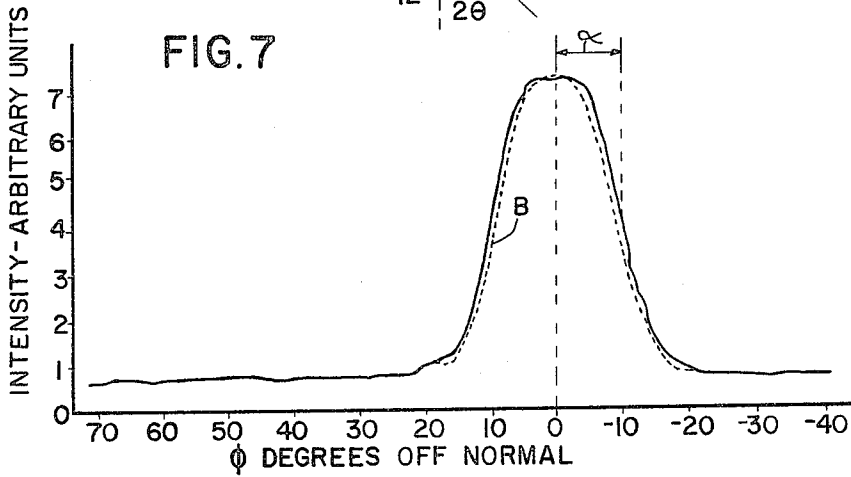
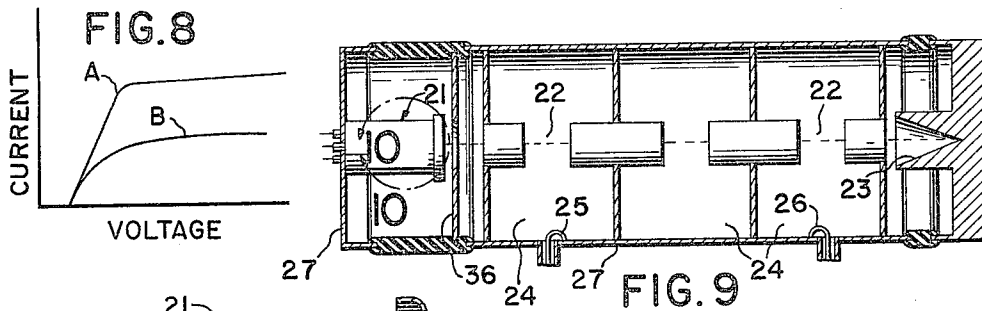
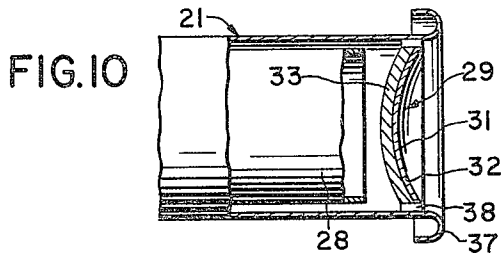
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4 Sheets-Sheet 2



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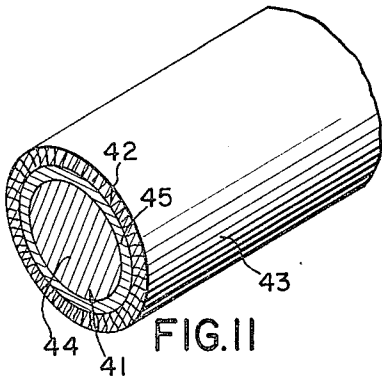


FIG. 11

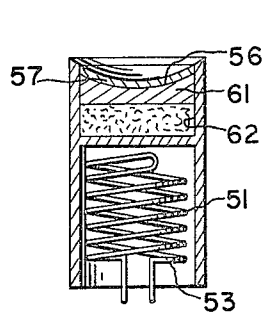


FIG. 12

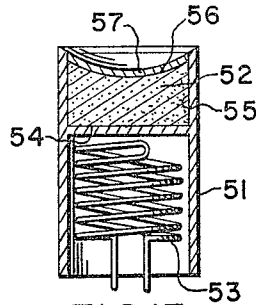


FIG. 13

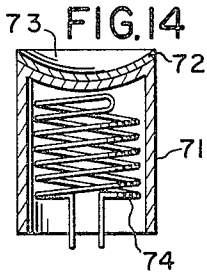


FIG. 14

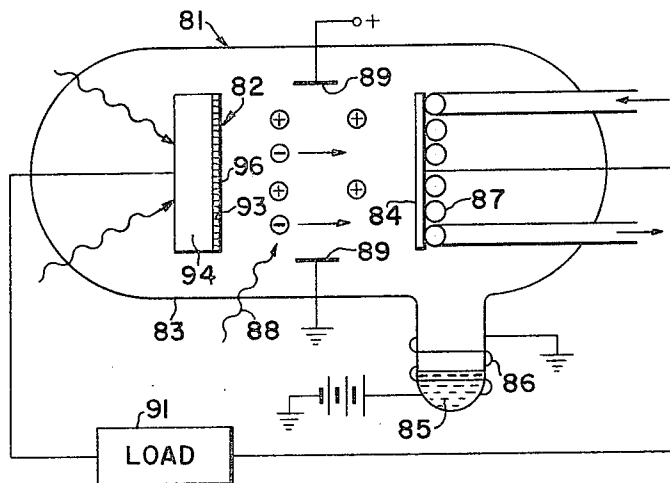


FIG. 15

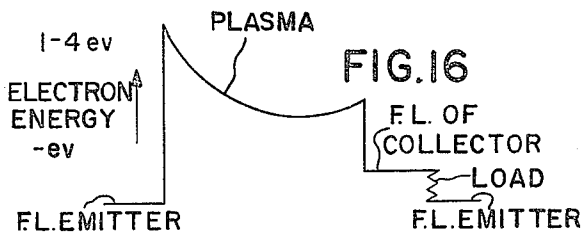


FIG. 16

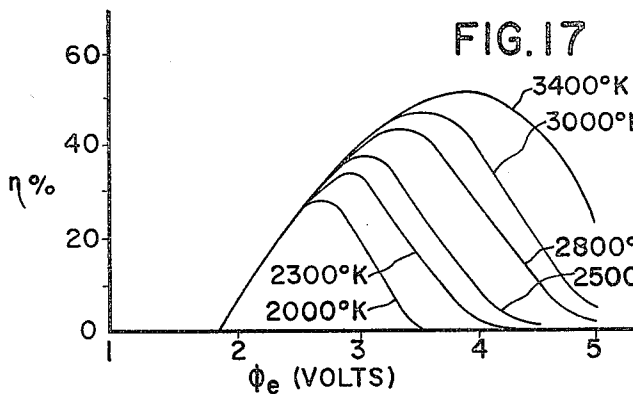


FIG. 17

CONVERSION EFFICIENCY η
AS A FUNCTION OF EMITTER
WORK FUNCTION WITH T_e
FOR A THERMIONIC
CONVERTER

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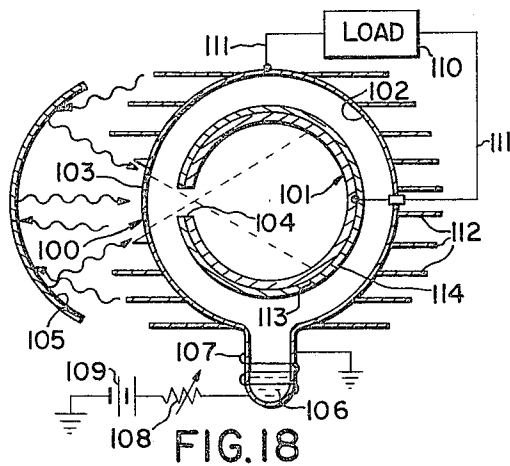
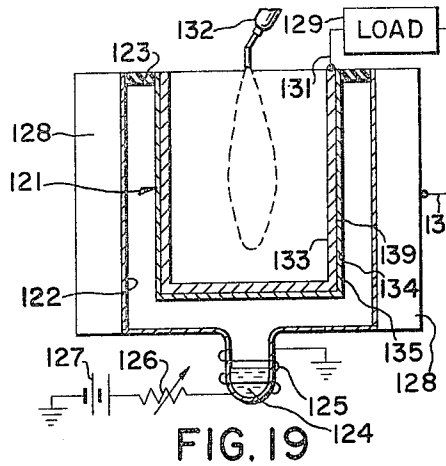
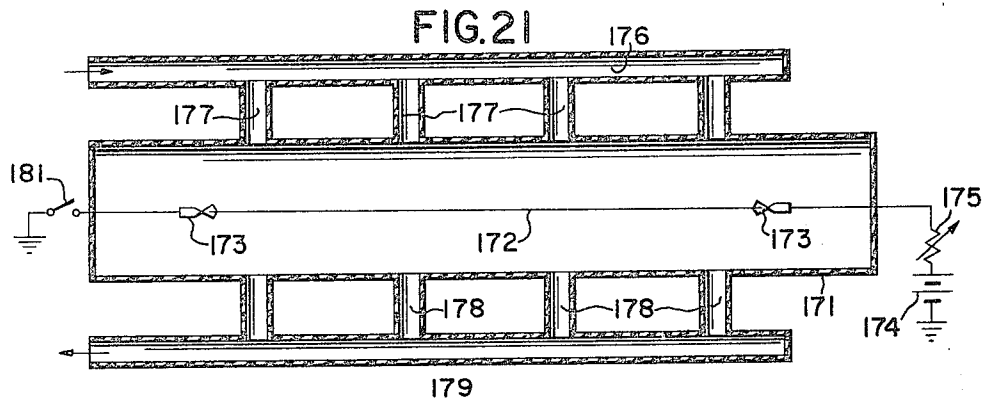
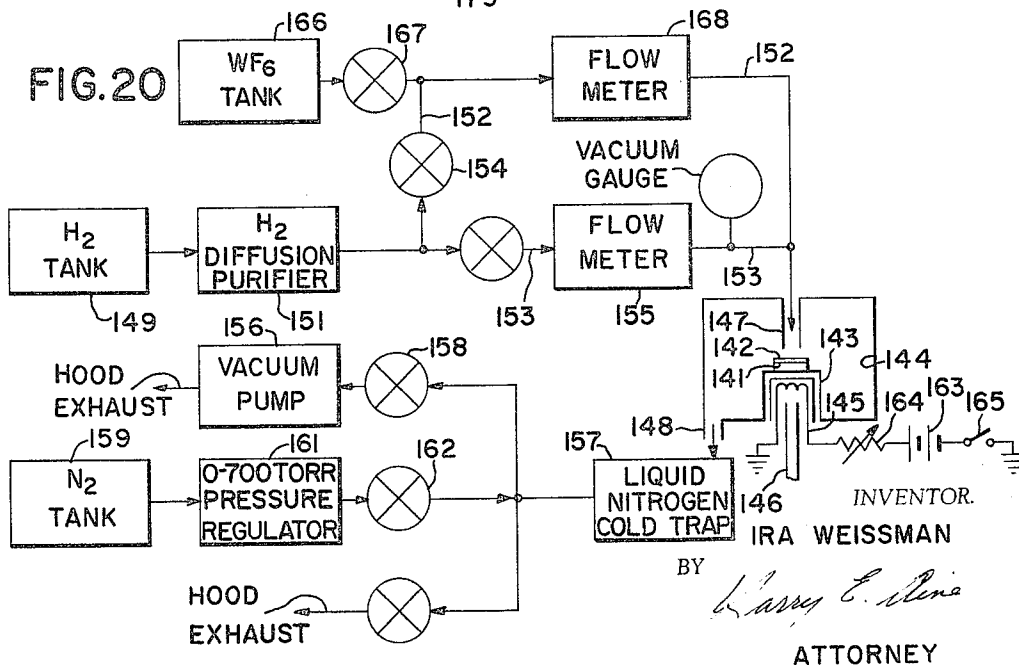
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4 Sheets-Sheet 4



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GRAIN-ORIENTED THERMIONIC EMITTER FOR ELECTRON DISCHARGE DEVICES

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Filed June 3, 1963, Ser. No. 285,150
19 Claims. (Cl. 313-346)

The present invention relates in general to thermionic emitters and more particularly to polycrystalline emitter members having a grain oriented emitting surface. Such emitters permit non-planar emitter surface geometries with greatly enhanced emission properties and are especially useful in electron discharge devices of all types including but not limited to klystrons, traveling wave tubes, magnetrons and thermionic converters.

Heretofore it has been known that certain crystallographic planes of a single crystal emitter such as the 111, 116 and 012 planes of body centered cubic tungsten gave much greater emission than other crystallographic planes such as, for example, the 110 and 112 planes. In a single crystal emitter body the high emission crystallographic planes are found in plane surfaces. Therefore, single crystals are not applicable to curved emitter surface geometries as required for most practical emitter applications. In addition, large single crystals are very expensive to fabricate.

Heretofore non-planar emitter surfaces have been fabricated using polycrystalline emitter bodies. The resulting emitter surfaces have been made up of a multitude of crystallites with a more or less random distribution of a great number of different crystallographic planes. Emitters having such random distribution of crystallographic planes at the surface are generally referred to as being "patchy" since their work function varies from one crystal plane to another. Patchy emitters are characterized by a large fraction of the emission coming from a small fraction of the total surface, that part being the part containing high emission (or low work function) crystal faces in the surface. The remaining large fraction of the emitter surface contributes essentially nothing to the total electron emission while nonetheless radiating thermal energy from the emitter thereby further contributing to inefficient emitter operation. For thermionic converter emitter applications patchy emitters are further undesirable because only a small part of the emitting surface can have the work function which corresponds to optimum efficiency at its operating temperature.

Heretofore certain polycrystalline thermionic emitters have had a small amount of crystallite ordering produced by cold working, casting, etc. The effect on uniformity of thermionic emission of ordering thus produced has been negligible.

In the present invention polycrystalline thermionic emitters are formed with highly grain oriented crystallites constituting the emitting surface thereby resulting in far more uniform emission and non-planar emitter efficiencies approaching those of a high emission crystallographic plane surface of a single crystal.

The term "grain oriented" as used herein shall mean that for almost all of the crystallites or grains that constitute the emitting surface, the normal to one particular crystal plane is oriented within a "specified angle," α , to the normal of a plane tangent to the emitting surface. The direction of the normal to the particular crystal plane in question shall hereafter be called the preferred crystal direction. The "specified" angle shall be sufficiently small such that the average current density obtained from the emitting surface is at least double the current density drawn from a comparable randomly oriented polycrystalline emitter operating under comparable conditions.

The "crystal direction" of the crystallites and the "specified" angle are conveniently measured by means of X-ray

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diffraction. A graph showing the integrated intensity of X-rays diffracted from the plane corresponding to the preferred direction as a function of angular displacement of the preferred direction from the surface normal will be called a distribution function (see FIG. 7).

The angle (α) between that at which the distribution function falls to $\frac{1}{2}$ its peak amplitude and that at which it has its peak amplitude is the "specified" angle referred to in the above paragraphs.

Grain oriented thermionic emitters, constructed according to the teachings of the present invention, will substantially increase the current densities obtained from emitters at a given temperature or allow the same emission at lower temperatures thereby increasing operating life. Use of thermionic cathode emitters of the present invention in thermionic converters, where uniform work function is particularly important, will lead to substantial increases in converter efficiencies from the low values of 10%–15% currently being obtained.

The principal object of the present invention is to provide improved thermionic emitters for use in electron tubes and to provide methods of fabricating such emitters.

One feature of the present invention is the provision of a novel polycrystalline thermionic emitter wherein the emitting surface is constituted of grain oriented crystallites whereby emitting efficiency is enhanced.

Another feature of the present invention is the provision of a polycrystalline thermionic emitter wherein the crystallites constituting the emitting surface are columnar with the columns oriented normal to the emitting surface whereby uniform emission is obtained from the emitting surface.

Another feature of the present invention is the same as the preceding feature wherein the crystallites form an overlay disposed upon a substrate.

Another feature of the present invention is the provision of a novel thermionic emitter according to the preceding feature wherein the overlay material is selected from the group of material including: thoria; rare earth oxides; carbides; borides; nitrides; and hexaborides.

Another feature of the present invention is the provision of a novel thermionic emitter according to any of the preceding features wherein the emitting surface is covered with an adsorbed thin film of material having a work function lower than that of the emitting surface said film being continuously replenished in use whereby the work function of the emitting surface is uniformly lowered.

Another feature of the present invention is the provision of a thermionic emitter according to any of the preceding features wherein the emitting surface is curved.

Another feature of the present invention is the provision of a polycrystalline thermionic emitter having a volt-ampere characteristic when tested in a diode characterized by an abrupt transition from fully space charge limited to fully temperature limited operation.

Another feature of the present invention is the provision of a novel electron discharge device employing a thermionic cathode emitter according to any one of the preceding features whereby device efficiency is enhanced and/or operating lifetime is increased.

Another feature of the present invention is the same as the preceding feature wherein the electron discharge device is a thermionic converter whereby conversion efficiency is enhanced and/or operating temperature is reduced.

Other features and advantages of the present invention will be more apparent after a perusal of the following specification taken in connection with the accompanying drawings wherein,

FIG. 1 is a line diagram defining certain crystallo-

graphic planes of a cubic crystal cell through the use of Miller indices,

FIG. 2 is a schematic isometric diagram of a single cubic crystal,

FIG. 3 is a graph of emission vs. crystallographic direction for the 110 zone of a single crystal of tungsten,

FIG. 4 is an enlarged schematic drawing of a fragmentary cross-sectional view of an emitter of the present invention having an electropolished polycrystalline grain oriented deposit on a polycrystalline substrate,

FIG. 5 is an enlarged fragmentary schematic drawing of a portion of the structure of FIG. 4 taken along line 5—5 in the direction of the arrows,

FIG. 6 is a schematic diagram depicting an X-ray diffraction method for determining the crystallographic plane distribution at and near the surface of the emitter,

FIG. 7 is a section taken through an X-ray diffraction pole plot of a certain crystallographic plane in a grain oriented surface layer constituting the emitting surface of FIG. 4,

FIG. 8 is a current vs. voltage curve for both the emitter of the present invention (A) and a typical prior art patchy emitter (B), both used in otherwise identical diodes,

FIG. 9 is a longitudinal cross-sectional view of a microwave electron tube utilizing a cathode emitter employing features of the present invention,

FIG. 10 is an enlarged fragmentary cross-sectional view of the emitter portion of FIG. 9 delineated by line 10—10,

FIG. 11 is an isometric view partly in cross-section of a filamentary emitter employing features of the present invention,

FIG. 12 is a longitudinal cross-sectional view of a thermionic dispenser emitter employing features of the present invention,

FIG. 13 is a thermionic dispenser emitter alternative of FIG. 12 employing features of the present invention,

FIG. 14 is a longitudinal cross-sectional view of a thermionic emitter of the coated type employing features of the present invention,

FIG. 15 is a schematic cross-sectional view of a thermionic converter electron tube employing features of the present invention,

FIG. 16 is an energy diagram depicting a possible mode of operation of a space charge neutralized thermionic energy converter,

FIG. 17 is a graph of thermionic converter efficiency as a function of the emitter work function for certain emitter operating temperatures and certain other special conditions,

FIG. 18 is a schematic longitudinal cross-sectional view of a thermionic converter employing emitter features of the present invention,

FIG. 19 is a schematic longitudinal cross-sectional view of a thermionic energy converter employing features of the present invention,

FIG. 20 is a schematic block diagram of chemical vapor deposition apparatus for obtaining uniform preferred crystallographic plane surfaces in grain oriented polycrystalline deposits, and

FIG. 21 is a longitudinal cross-sectional view of an alternative chemical vapor deposition chamber.

Referring now to FIG. 1 there is shown a cubic cell with the conventional orthogonal coordinate system wherein the axes are labeled x , y , and z . Crystallographic planes are conventionally defined by an index system utilizing "Miller Indices" and fully described in Introduction to Solid State Physics, by Kittel, 2nd edition, published 1956, pages 33 et seq. Briefly, the Miller Indices are three numbers (h , k , l) corresponding to the reciprocals of the points of intersection of the identified plane with the x , y , and z axes, respectively. In FIG. 1 the (100), (110), (111), and (210) crystallographic planes are depicted and identified. The crystal direction as previously defined is normal to a certain crystallo-

graphic plane and is identified by the same triplet of Miller Indices as is that plane (e.g. the 110 crystal direction is the direction normal to the 110 crystal plane).

FIG. 2 shows a single crystal of a cubic material such as tungsten or molybdenum. The crystal is formed by an ensemble of cubic cells. The cells are uniformly arranged and any arbitrary planes cut through the crystal will expose a surface constituted of a single crystallographic plane. Note that a surface constituted of a single crystallographic plane can not be obtained over a curved surface of the single crystal. Thus any curved surface taken through the single crystal is not uniform in the sense that different crystal faces are exposed over it.

FIG. 3 shows the emission from the different crystallographic planes of the 110 zone of a single crystal of tungsten as measured by G. F. Smith, Physical Review, vol. 94, page 295 (1954). Emission peaks are shown for the (111), and (116) crystallographic planes. Lowest emission was obtained from the (110) planes. The (116) plane corresponds to the lowest work function of 4.30 ev. and the (110) plane corresponds to the highest work function of 6.00 ev. The work function for the (111), (100), and (012) planes are 4.39 ev., 4.53 ev., and 4.34 ev., respectively. While the preferred planes of a single crystal emitter can be exploited at high cost for planar emitter geometries they are not applicable to non-planar geometries as found in most all emitter applications.

Polycrystalline thermionic emitters are ordinarily used in making curved emitting surfaces but these have heretofore been plagued with non-uniform or patchy emission. The principal cause of non-uniform emission from polycrystalline metals is the difference in work function of the various crystallographic planes that constitute the emitting surface. The average work function for a randomly oriented polycrystalline tungsten emitter is 4.52 ev. or about 0.2 ev. higher than the highest emission (116), crystallographic plane of a single crystal tungsten emitter. It should be noted that in the normal operating range of practical emitters a 0.1 ev. change in work function corresponds to 60° K. change in operating temperature for the same emission. Also that a 10% change in work function produces a ten fold change in emission at the same operating temperature. Patchy emitters typically have work function variations over them of the order of 10%. Thus low work function regions, though they may represent a relatively small fraction of the total surface area, will produce a large fraction of the total emission, while high work function areas will, relatively speaking, be thermionically dead.

Table I illustrates the approximate improvement that could be realized if the total surface were made uniformly low work function, starting with various patchy surfaces having both high and low work function regions. In this approximation interpatch effects are neglected.

TABLE I

Initial Fractional Area Of High Emission Surface	Contribution To Total Emission Produced By Fractional Areas Of High Emission ¹	Available Increase In Emission By Making Total Surface Of High Emission ¹
1/20	1/3	700%
1/10	1/2	500%
1/5	2/3	350%
1/2	10/11	200%

¹ Assuming a 10% difference in work function between the high emission area and low emission area of the total emitting surface.

Referring now to FIG. 4 there is shown a fragmentary cross-sectional view of a filamentary emitter constructed according to the teachings of the present invention. More particularly, a refractory metal wire or substrate 11 as of, for example, tungsten, molybdenum, rhenium, niobium, tantalum, etc. is overlaid with a layer 12 of grain orient-

ed polycrystalline refractory material as of, for example, one or more of the aforementioned refractory metals.

Although a number of different methods may be suitable for forming the grain oriented layer 12 a preferred method is that of chemical vapor deposition. This preferred method of deposition will be more fully described below and illustrated by FIG. 20.

In a typical example of a filamentary emitter structure (FIG. 4) of the present invention, a 0.006" diameter tungsten wire 11 is overlaid with a 0.0005" thick deposit of grain oriented tungsten by chemical vapor deposition from a constituent gas atmosphere of tungsten hexafluoride and a hydrogen reducing gas. By proper control of the thermodynamic and fluid dynamic parameters of the vapor deposition process a uniform growth of tungsten crystallites 12 is obtained over the outside of the tungsten wire 11. The crystallites are elongated in the direction normal to the surface of the substrate wire 11 such as to form a grain oriented columnar structure with the columns being normal to the outside surface of the emitter. By proper control of deposition temperature, pressure, gas mixture, etc. the crystallite grains are oriented.

The outer surface of the deposited overlay is typically initially rough and possibly constituted of many different crystallographic planes. These surface irregularities are removed by, for example, electropolishing to expose the crystallographic planes 13 normal to the grain axes. In this manner the oriented crystallographic planes are exposed at the outer surface of the overlay 12 constituting the emitter surface. A preferred electropolishing method is described below in connection with the description of FIG. 20.

An indirect check of the distribution of crystallographic planes at the emitting surface can be obtained with X-ray diffraction as indicated in FIGS. 6 and 7 using a Norelco pole figure plotter. Briefly, an X-ray generator 14, disposed in the Y-Z plane, projects a well collimated X-ray beam of characteristic K α radiation onto the emitting surface 13 of an overlay 12. The overlay forms a plane surface parallel to the Y axis and is rotatable about the Y axis through angles ϕ . An X-ray detector 15 as, for example, a Geiger counter is positioned in the Y-Z plane to receive X-ray energy reflected from the overlay 12. The X-ray detector 15 is arranged to receive reflected X-ray energy from the sample 12 substantially only from the same angle θ with the Y axis as the incident X-ray beam makes with the Y axis. The flat emitter layer 12 is also rotatable through angle ω about an axis, N, perpendicular to the plane of layer 12. Plots of integrated intensity of received X-ray energy as a function of ϕ are made.

The angle θ uniquely determines the crystallographic plane that will be detected by the intensity of the diffracted signal according to the Bragg law, $\lambda = 2d \sin \theta$. The crystallographic plane, in the polycrystalline layer 12, of special interest is the plane parallel to the emitting surface since the emitting surface will be constituted of this plane when the surface has been properly smoothed and polished as verified by Khan et al., Physical Review, vol. 129, No. 4, February 15, 1963, page 1514.

A section taken through a pole plot of the (100) plane for a grain oriented tungsten deposit is shown in FIG. 7. This plot shows that the (100) plane of the deposited polycrystalline layer is predominately disposed parallel to the surface.

In addition to identifying the preferred crystal plane, the pole plot describes its distribution within almost the entire hemisphere about the surface normal. The half width (2α) of the plotted distribution is a meaningful measure of the degree of preferred orientation. The plot of FIG. 7, for an actual deposit, shows a typical half width of its distribution of approximately 20° with a peak intensity of 22 units. All plots thus far obtained for chemically vapor deposited tungsten have been cylindrically symmetric about the surface normal, N indicating no preferred orien-

tation in the plane of deposition. Therefore, a single section of the full plot, for all angles of ϕ from 90° to -90° as in FIG. 7, defines the surface everywhere in the hemisphere.

A mild heat treatment, 1900° C. for 30 minutes, tends to improve the uniformity of the deposited surface. The distribution for the treated surface is shown as curve B in the plot of FIG. 7. FIG. 8 illustrates comparative volt-ampere characteristics of high vacuum diodes, identical in every respect except that one utilizes a grain oriented polycrystalline filamentary emitter and the other an ordinary polycrystalline emitter. Plot B shows the emission characteristics of the patchy filamentary emitter. Plot A shows the emission characteristics of the uniform work function polycrystalline emitter. The sharpness or abruptness of the "knee" of plot A shows the high degree of uniformity of the emission from the grain oriented emitter. The more the uniformity of the emissive surface the more abrupt the transition from fully spaced charge limited to fully temperature limited emission.

Surfaces which exhibit more uniform emission by the above criterion in vacuum, also exhibit more abrupt transitions from the retarding field region into the temperature limited accelerating field region when operating space charge neutralized in a low pressure positive ion atmosphere as encountered in some thermionic energy converters. Surface uniformity in thermionic converter emitters is very important and the advantages to be gained by such uniformity will be more fully described below with regard to the thermionic converter embodiment of FIG. 15.

The work function of the aforementioned uniform work function vapor deposited polycrystalline emitter, as measured from a positive ion neutralized diode volt-ampere curve, was 4.56 ev. This agrees almost perfectly with the accepted value of 4.53 ev., for the work function of the (100) crystal plane of a single crystal of tungsten. The diffraction pole figure plot of the deposit indicated a grain oriented surface with the (100) crystal plane oriented parallel to and constituting the emitting surface.

An electron tube incorporating a cathode emitter constructed according to the present invention is shown in FIGS. 9 and 10. The tube includes a cathode assembly 21 at one end for forming and projecting a beam of electrons over an elongated beam path. A collector electrode 23 is disposed at the terminal end of the beam for collecting the electrons and dissipating their energies.

A plurality of cavity resonators 24 are successively arranged along the beam path in R.F. energy exchanging relationship with the beam passable therethrough. The cavity resonators 24 are disposed intermediate the cathode 21 and collector 23. The upstream resonator includes an input terminal 25 for applying input R.F. signals to be amplified to the input resonator. The last or downstream resonator includes an output terminal 26 for extracting amplified R.F. wave energy from the tube. A vacuum envelope 27 surrounds the aforementioned tube elements for maintaining a suitable low vacuum as of 10^{-7} mm. Hg within the tube apparatus. The tube operates in the manner of the conventional klystron amplifier.

The cathode assembly 21 includes a Pierce type electron gun assembly and an electron bombarder type cathode heater 28. The primary thermionic emitter member of the electron gun consists of a concave circular emitter member or structure 29 formed from a disk having a spherical concavely shaped segment forming the emitting surface 31. The concave emitting surface 31 is constituted of a grain oriented polycrystalline refractory metal layer 32 to obtain uniform and enhanced emission as compared to randomly oriented polycrystalline emitters.

In a preferred embodiment the metal layer 32 is deposited on a concave refractory or high melting point

material substrate 33 preferably as of, for example, tungsten or thoriated tungsten. The grains of the layer 32 are preferably elongated into columnar form with their longitudinal axes directed normal to the surface of the substrate and to the concave emitting surface 31. The crystallites of the layer 32 are oriented such that emission is enhanced.

The heater 28 bombards the back side of the substrate 33 with electrons of substantial energies as of 2500 ev. to heat the cathode emitter to its operating temperature of approximately 2000° C.

A centrally apertured anode electrode 36 is spaced from the emitter 29 and operated at a suitable positive potential relative to the cathode emitter as, for example, +17.5 kv. The anode 36 is provided with a flared aperture in axial alignment with and coaxially disposed of the cathode emitter 29 for drawing therethrough a converging electron stream.

A cylindrical focus electrode 37 as of tantalum surrounds the outer periphery of the concave emitter button and serves to support the emitter 29 via the intermediary of a plurality of inwardly directed tangentially contacting fingers 38 as of tantalum spot welded at their ends to both the focus electrode 37 and emitter button 29.

The advantage of the uniform thermionic emitter surface as above described is that it permits the tube to operate at higher power levels for the same cathode operating temperature previously used for patchy emitters or it permits the same power output at lower cathode operating temperature thereby substantially increasing tube operating life as compared to tubes using patchy emitters.

Referring now to FIG. 11 there is shown an isometric view of a thermionic emitter embodiment incorporating features of the present invention. More particularly, a thoriated tungsten emitter member 41 is overlaid with a deposit 42 of a grain oriented refractory metal, as described above, to obtain more uniform and enhanced emission from the emitting surface 43.

This embodiment is illustrative of the wide variety of possible substrate materials to which the grain oriented overlay may be adhered to obtain uniform emission characteristics. The improved thermionic emitter structure of FIG. 11 uses, in addition to the surface uniformity features of the present invention the porosity feature of the polycrystalline grain oriented overlay. This porosity feature permits a low work function material as, for example, thorium to continuously diffuse through the grain boundaries, to the surface and to diffuse over the surface of the emitter to uniformly lower the work function of the emitting surface 43. This latter type of improved emitter forms the subject of and is claimed in applicant's copending application, U.S. Serial No. 367,183 filed May 13, 1964, titled, "Thermionic Emitter and Method of Fabricating Same," and assigned to the same assignee as the present invention.

In a typical example of the thoriated tungsten emitter of FIG. 11 the thoriated tungsten substrate 41 is formed of a 0.006" diameter thoriated tungsten wire 44 carburized at its outer surface layer 45 as by, for example, passing hydrogen gas saturated at room temperature with xylene vapor over the heated (~1700° C.) thoriated tungsten substrate wire. Carburization is complete at the point in time when the total resistivity of the wire has changed by 10% of its initial value. The grain oriented overlay 42 is deposited directly over the carburized substrate layer 45 to a depth of, for example 0.0001" to 0.001" by the method of chemical vapor deposition more fully described below with regard to FIGS. 20 and 21.

The surface 43 of the vapor deposited layer 42 is smoothed such as by, for example, electropolishing as described below, to remove surface irregularities and to expose the uniformly grain oriented emitting surface.

The emitter is activated as by, for example, directly

heating the emitter wire by passing electrical current therethrough. The temperature of the emitter during activation can be near its typical operating temperature such as, for example, 1600° C. to 1650° C. The activation time (for the above example ~120 minutes) should be sufficient to cause enough thorium to diffuse to and over the surface such that surface coverage is adequate to yield emission from the emitter typical of that from a single crystal face of tungsten with a monoatomic layer of thorium over its surface.

In operation, at the typical operating temperature of 1600° C. to 1650° C., thorium is desorbed at the surface but is continuously replenished by diffusion of thorium from the thoriated tungsten substrate through the grain boundaries of the grain oriented layer 42 to continuously provide a nearly monoatomic layer of thorium at the surface. The monoatomic surface coverage of thorium lowers the work function of the emitting surface 43 of the layer 42 to, for example, 3.0 ev. in the same manner as any typical electropositive adsorbed surface layer.

The term "emitting surface" as used herein shall be deemed to be the emitter surface from which electron emission issues exclusive of adsorbed thin films on order of a few atoms or molecules thick.

Greatly enhanced emission is realized from the aforementioned thoriated tungsten emitter of FIG. 11. More specifically a 400% increase in emission was obtained from an emitter of FIG. 11 with a (100) crystallographic plane of tungsten constituting the emitting surface as compared to an identical emitter, at the same temperature, except that the latter emitter had a typical patchy emitting surface. By deposition of the (111) crystallographic plane, as opposed to the (100) plane constituting the emitting surface, a 1000% or greater increase in emission is obtainable over that of the patchy emitter.

Referring now to FIGS. 12 and 13 there are shown two alternative dispenser cathode embodiments utilizing the surface uniformity feature of the present invention. In addition, as in the previous embodiment of FIG. 11, these dispenser thermionic emitters also employ the porosity feature of the grain oriented layer permitting low work function materials such as barium, thorium, etc., to be stored within the emitter body and to diffuse through the grain boundaries of the deposited layer to supply a continuous monoatomic or monomolecular coating of low work function material to the polycrystalline emitter surface constituted of grain oriented crystallites. This improved type of thermionic dispenser emitter forms the subject of and is claimed in applicant's copending application, U.S. Serial No. 367,183 filed May 13, 1964, titled, "Thermionic Emitter and Method of Fabricating Same," and assigned to the same assignee as the present invention.

The thermionic dispenser emitter structure of FIG. 12 includes, a tube 51 of refractory metal as of molybdenum closed at one end by a porous refractory metal disk 52 or matrix as of sintered tungsten or nickel impregnated with a fused mixture of barium oxide and aluminum oxide in a 5:2 mol. ratio. The fused mixture completely or partially fills all voids and interstices of the porous disk 52 which are accessible from the exterior of the disk 52.

A heater 53 is mounted within the tube for heating the cathode. In order to reduce evaporation of the alkaline earth metal and its diffusion into the molybdenum tube 51 the underside 54 and sides 55 are lapped to close the pores prior to impregnation of the disk 52 with the alkaline-earth metal composition.

The porous body 52 is machined at its outer surface 56 to provide a surface conforming to the shape of the desired emitting surface. In some cases, as in a Pierce gun, this surface is spherically concave. In other cases, the surface 56 is flat.

A grain oriented layer 57 of a high melting point material and preferably a refractory metal is deposited, as by chemical vapor deposition, on the surface 56. The columnar crystallites or grains of the deposited layer 57

are preferably oriented normal to the surface 56 and deposited, as described more fully below, such that a certain preferred crystallographic plane is disposed normal to the columns which is tantamount to being in the emitting surface. In this manner the emitting surface is uniformly constituted of the preferred crystal plane. The surface layer 57 is of any suitable thickness as of, for example 0.0001"—0.001".

After depositing the layer 57 it is preferably polished by any suitable means and preferably electropolished, as described below, to expose uniformly the oriented crystallites. The porous impregnated body 52 with the deposited layer 57 is mounted within the tube 51 as by welding and mounted in an evacuated envelope. After degassing the envelope, the cathode is activated by operating the emitter at a temperature somewhat higher than normal operating temperature, e.g., 1000° C. to 1200° C. until the cathode emits satisfactorily.

In operation, the impregnate alkaline earth composition, at elevated operating temperature, reacts with the refractory metal, principally in a manner productive of free alkaline earth metal. The alkaline earth metal diffuses out of the porous refractory matrix to the surface of the deposited layer through the oriented grain boundaries of the deposited layer 57. At the emitting surface of the polycrystalline grain oriented layer 57 the alkaline metal diffuses over the surface of the layer 57 to supply a layer of alkaline earth metal substantially one molecule thick on the surface.

Instead of machining the body in the manner described above, the body may be impregnated with a filler metal, swaged, or rolled and drawn to a reduced diameter in order to produce filaments which may be processed into cathodes. Likewise the body of refractory metal may be formed by extrusion and impregnated with filler metal or powdered refractory metal may be mixed with powdered filler metal and the body pressed and sintered.

As impregnant materials those which are capable of reacting with the refractory metal principally in a manner productive of free alkaline earth metal are particularly suitable. As refractory metals, tungsten is preferred but molybdenum, tantalum, niobium and rhenium among others, may be used. In the case of tungsten, certain alkaline earth compounds, notably the nitrates react therewith to form tungstates, with a consequent diminution of the amount of free alkaline earth metal being made available in the free state. It is probable that similar reactions occur with the other refractory metals and for that reason we prefer to use no nitrates of the alkaline earth metals.

The porous refractory metal body 52 may be impregnated by a number of different methods using a number of different materials as described in the following U.S. patents: 2,700,000, 2,700,118, 2,716,716, 2,769,708 2-813,807 2,848,644, and 2,929,133.

Such impregnants include, mixtures of alkaline earth metal azides and/or hydrides with a compound selected from formates and carbonates, mixtures of alkaline earth metal tungstate and a reducing metal selected from the group of thorium, zirconium, and tantalum, and other mixtures.

Referring now to FIG. 13 there is shown an alternative dispenser emitter embodiment. In this embodiment the emitters are substantially the same as described with respect to FIG. 12 and like numerals have been applied to identical elements. In this instance the grain oriented overlay 57 is deposited upon a porous refractory metal disk 61 as of sintered powdered tungsten which closes off a cavity 62 containing an alkaline earth composition and forming a reservoir of low work function materials. Suitable compositions include materials which are capable of reacting with the refractory metal disk 61 principally in a manner productive of low work function free alkaline earth metal.

The low work function material such as, for example, barium or thorium diffuses through the porous disk 61

and thence through the overlay 57 to the emitting surface. At the emitting surface the low work function metal replenishes the desorbed low work function metal to maintain a uniform low work function emission surface.

Referring now to FIG. 14 there is shown an alternative embodiment of the present invention wherein the surface uniformity feature of the present invention is applied to advantage in a thermionic emitter of the coated type. In this type of thermionic emitter structure a coating of material capable of providing copious emission is deposited upon a high melting point material base member as of, for example, nickel, tungsten or tantalum.

Suitable coating materials providing copious emission at relatively low temperatures as of 1400° C. include: thoria, rare earth oxides such as, for example, yttrium oxide, gadolinium oxide, dysprosium oxide, and many others; and certain carbides, borides, and nitrides such as, for example zirconium carbide, thorium carbide, and uranium carbide, uranium nitride, and certain of the hexaborides such as lanthanum hexaboride and neodymium hexaboride.

According to the teachings of the present invention the emissive coating, as of one of the aforementioned materials, is deposited, as by chemical vapor deposition, upon a high melting point material base member 71 as of, for example, nickel to form a polycrystalline emissive layer 72 tenaciously adhering to the base member 71.

The emissive layer 72 is a grain oriented deposit. In a preferred embodiment the emitting surface 73 is electropolished to remove surface irregularities and to uniformly expose the preferred crystal planes of the oriented crystallites.

A heater 74 is carried within the base member 71 for heating the emitter to its operating temperature of approximately 1400° C.

Referring now to FIG. 15 there is shown, in schematic form, a thermionic energy converter 81 employing a thermionic emitter 82 embodying features of the present invention. Briefly, the thermionic energy converter 81 includes a gas tight enclosure or envelope 83 as of glass or alumina ceramic. A thermionic emitter structure 82, more fully described below, is disposed opposite and spaced from a collector electrode 84 as of tungsten. A positive charge carrying medium such as ionized cesium, potassium, rubidium or noble gas vapor at, for example, 0.01 mm. Hg fills the envelope 83 for neutralizing the electron space charge at the emitting surface of the emitter 82 and in the space between emitter 82 and collector 84.

The neutralizing gas vapor is provided by a reservoir 85 containing liquid neutralizing metal such as cesium, potassium or rubidium in gas communication with the envelope 83. The reservoir 85 is heated via heater 86 to vaporize a sufficient amount of liquid metal to maintain the desired operating vapor pressure in the envelope 83.

The emitter 82 is heated to operating temperatures as of 1600° C. via any suitable means such as by flame, solar energy or nuclear energy serving to heat the back side of the emitter structure 82.

The collector is cooled by any suitable means such as, for example, by radiation and/or conduction. In the example, cooling coils 87 carrying a fluid coolant circulating therethrough are affixed to the back side of the collector electrode 84.

The neutralizing medium may be ionized by any suitable means as, for example, by surface ionization from the emitter 82 or other electrodes, by photon impact, indicated at 88, wherein high energy photons pass through the wall of the envelope 83, or by an electron discharge between a pair of electrodes 89.

A utilization device or load 91 is connected in the circuit between the emitter and collector electrodes 82 and 84.

In operation, the emitter is heated to its operating tem-

perature as of 1600° C. Electrons boil out of the emitting surface with sufficient thermal energy to overcome the work function of the emitter surface as of 1-4 ev. (see FIG. 16). The space charge is neutralized by the positive ions or plasma in the space between the emitter and collector electrodes 82 and 84, respectively. The electrons because of their initial thermal velocities and any additional velocity added by positive space charge adjacent the cathode emitter 82 traverse the space to the opposed collector electrode 84 where they pass through a lesser negative collector work function thereby dropping to the Fermi level of the collector. Under typical operating conditions the energy lost by the electron in falling to the F.L. of the collector is less than the thermal energy they acquired in leaving the emitter. Thus they still possess energy which they deliver to the load 91 in returning back to the emitter.

In the thermionic converter 81 of the present invention the thermionic emitter structure 82 is formed by a polycrystalline layer 93 of grain oriented high melting point material and preferably a refractory metal as of, for example, tungsten, or molybdenum, deposited as by, for example, chemical vapor deposition, upon a refractory substrate 94 as of tungsten. In this manner the emitting surface 95 is uniformly constituted of grain oriented crystallites. The surface layer 93 is of any suitable thickness as of, for example, 0.0001" to 0.001" thick. After deposition of the layer 93 it is preferably smoothed as by, for example, electropolishing as described below, to uniformly expose the preferred crystallographic planes of the oriented crystallites by removing surface irregularities.

The advantageous result obtained by removing the patchiness of the emitting surface, in the above manner, can be seen by reference to FIG. 17 (graph from Hernquist et al., RCA Revue, June 1958) wherein there is shown a graph of converter efficiency as a function of emitter surface work function and temperature for a tungsten emitter. The graph clearly shows that for a given emitter temperature T_e there is an optimum emitter work function ϕ_e . If the emitter surface is patchy then only a small fraction of the emitting surface will have a work function corresponding to the optimum. However, if the emitting surface is uniform, i.e., is constituted of one grain orientation, as in the present invention, then this emitter surface will be characterized by a uniform work function. Therefore, the entire emitting surface can be made to have the optimum efficiency by merely operating the emitter at the temperature for which this uniform work function yields optimum converter efficiency. In this manner the converter efficiency is greatly enhanced.

The thermionic emitter 82 of FIG. 15 is characteristic of a class of thin film thermionic emitters wherein a thin film (monolayer) of low work function material which is adsorbed onto the emitting surface is continuously replenished from a vapor, in this case cesium, potassium or rubidium, in equilibrium with the emitting surface 96. The adsorbed monoatomic layer of material lowers the work function of the crystallographic planes of the emitting surface 96 to a work function typical of a single crystal face coated with a monolayer of the film. If the coating becomes sufficiently thick as, for example, in the order of 5 to 10 atoms thick then the surface will take on the work function of the coating material.

It should be noted that all crystallographic planes do not uniformly adsorb the thin film. The adsorption mechanism is dependent upon the atomic spacings in the exposed surface, both directly, since they affect the packing of the adsorbed atoms, and indirectly on account of the value of the work function. Thus cesium is adsorbed preferentially on the highest work function faces of tungsten, the (112) and the (110) faces, since the indirect effect is the greater, whereas barium and thorium are adsorbed preferentially on the (111) face, which has the lowest work function, because with them the direct effect is the greater.

Referring now to FIGS. 18 and 19 there are shown two thermionic converters utilizing non-planar uniform thermionic emitters using features of the present invention.

FIG. 18 shows in schematic form a thermionic converter of spherical geometry. More specifically, a hollow spherical thermionic emitter structure 101 is surrounded by a hollow spherical anode 102 also serving as the gas tight envelope. Aligned apertures 103 and 104 are placed in the anode 102 and emitter 101, respectively, to permit ingress of thermal energy focused through the openings 103 and 104 via mirror 105. The outer opening 103 is covered over by a heat permeable gas tight window member 100 as of sapphire. The thermal energy is received internally of the emitter for heating thereof to the operating temperature.

An electropositive atmosphere as of, for example, ionized cesium at .01 torr pressure fills the spherical annulus between anode 102 and cathode 101 for space charge neutralization.

The cesium is supplied to the annulus from a reservoir 106 in gas communication with the annulus. The pressure of the cesium vapor is controlled via heater coil 107, variable resistor 108 and battery 109.

The load 110 is connected in the circuit between and external of anode 102 and cathode 101 via leads 111. Heat radiating fins 112 are carried external of the anode 102 for cooling thereof.

The thermionic emitter cathode 101 is provided with an external layer 113 of columnar grain oriented refractory material with the columns oriented normal to the external surface 114. The layer 113 is deposited such that the surface 114 is constituted of grain oriented crystallites, as previously described, such that a uniform non-patchy polycrystalline emitting surface is formed to enhance converter efficiency as previously described with regard to FIG. 15.

Referring now to FIG. 19 there is shown an improved thermionic converter of generally cylindrical geometry which incorporates a thermionic emitter of the present invention.

More specifically, a hollow cylindrical thermionic emitter 121 is coaxially surrounded in spaced relation by a hollow cylindrical collector 122 also serving as the gas tight envelope. An annular insulator 123 holds the cathode emitter 121 in spaced insulated relationship from the collector 122. A reservoir 124 for liquid metal as of cesium, or rubidium is disposed in gas communication with the annulus between collector 122 and cathode emitter 121 for providing a low pressure atmosphere of neutral plasma in the space between collector and cathode. A heater assembly including a heater coil 125, variable resistor 126 and battery 127 serve to control the gas pressure within the converter.

The collector electrode 122 is provided with a plurality of outwardly directed fins 128 for cooling the collector via radiation and convection. An external load 129 is connected in the circuit between the thermionic emitter 121 and the collector 122 via leads 131.

The thermionic emitter 121 is heated to its operating temperature of approximately 1300° C. via a torch 132 directing its flame into the hollow interior of the emitter 121.

The emitter includes a hollow cylindrical substrate member 133 as of polycrystalline tungsten with an overlay 134 of grain oriented polycrystalline high melting point material and preferably a refractory emitter material as of tungsten. The grains of the overlay 134 are predominately oriented normal to the external surface 135 of the emitter 121, as described with regard to FIG. 15, to obtain a uniform non-patchy emitting surface 135.

The thermionic converter of FIGS. 15, 18 and 19 use space charge neutralization combined with thin film emission from the thermionic emitter. In an alternative embodiment, not shown, converter geometries are generally the same on FIGS. 15, 18 and 19 except that the envelope

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containing the converter elements such as emitter and collector is evacuated to a relatively high vacuum as of 10^{-6} mm. Hg. In addition, spacing between the thermionic emitter and the collector is greatly reduced to a very close spacing, i.e., in the order of 0.0001" such that this alternative converter operates space charge limited in accordance with Child's law; namely,

$$i \propto \frac{V^{3/2}}{d^2}$$

where V is approximately the difference in Fermi levels between emitter and collector, d is the distance between emitter and collector, and i is the current density. The surface uniformity feature of the present invention is as equally applicable to the latter space charge limited converter as to the space charge neutralized converter, previously described, for obtaining enhanced thermionic converter efficiency.

Referring now to FIG. 20 there is shown in schematic diagram form apparatus for chemical vapor deposition of uniform grain oriented overlays. More specifically, a substrate member 141 upon which it is desired to deposit an overlay 142 of grain oriented material is disposed upon a pedestal 143 as of stainless steel in a closed deposition chamber 144 as of stainless steel having a suitable volume as of, for example, 1 liter.

A heater filament 145 is disposed inside the hollow cylindrical pedestal 143 for heating the pedestal 143 and substrate member 141 to a deposition temperature, more fully described below. A coolant conduit 146 terminates adjacent the back side of the pedestal 143 for selectively directing a flow of coolant onto the heated pedestal for rapid cooling thereof, as described below. A vapor inlet conduit 147 as of $\frac{3}{8}$ " diameter tubing is set above the substrate to direct the flow of vapor uniformly over the substrate 141. Vapor is exhausted from the chamber 144 via exhaust tubulation 148.

The (100) crystal direction of tungsten is oriented normal to the emitting surface in the following manner:

Hydrogen gas as drawn from a high pressure tank 149 is purified via purifier 151 and fed via parallel conduits 152 and 153 to the deposition chamber 144 for flushing the system to remove oxygen and water vapor from the conduits 152 and 153 and deposition chamber 144. A five minute flush at room temperature is sufficient.

Parallel conduit 152 is closed to the hydrogen source by closing valve 154. The flow of hydrogen reducing gas into the deposition chamber 144 from the tank 149 is set to a suitable flow level, as monitored by flow meter 155. A typical flow rate of hydrogen into a 1 liter chamber 144 is 1.5 liters per minute.

A vacuum pump 156 as, for example, a small 5 liter per second mechanical pump is connected to exhaust the deposition chamber 144 via exhaust tubulation 148, liquid nitrogen cold trap 157 and valve 158. The vacuum pump is started and the deposition chamber 144 is pumped down to 400 torr. The 400 torr pressure is maintained by means of a ballast system including a tank 159 of high pressure nitrogen gas connected into the input line of the pump 156 via a pressure regulator 161 and valve 162. The pressure regulator feeds sufficient nitrogen ballast gas into the pump 156 to maintain the pressure within the deposition chamber 144 at the desired pressure as of 400 torr.

The substrate member 141 is brought up to deposition temperature as of, for example, between 500° C. and 800° C. and preferably 600° C. via heater 145 supplied with current from battery 163 via variable resistor 164 and switch 165. A thermocouple (not shown) embedded in the pedestal 143 measures the temperature of the pedestal.

Tungsten hexafluoride gas is fed into the deposition chamber from a high pressure tank 166 via valve 167 and flow meter 168. The flow of tungsten hexafluoride gas is controlled via valve 167 such that the ratio of the hydrogen flow rate to the tungsten hexafluoride flow rate into the chamber 144 is, for example, between 5.3 and 11

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and preferably 10. When the ratio is 10 the flow rate of the tungsten hexafluoride gas into the chamber 144 is, for example, 0.15 liter per minute.

The deposition is continued for a time sufficient to deposit the desired thickness of grain oriented overlay 142 as, for example, five seconds for 0.00025" thickness of overlay. Typical overlays range between 0.0001" to 0.001".

Deposition is terminated by rapidly cooling the deposition surface below the deposition temperature while maintaining the flow of constituent gases. For example, in the instant case the substrate is rapidly cooled, i.e., in one to two seconds from 600° C. to 400° C. by a water blast directed from the coolant tube 146 onto the back side of the pedestal 143, after the heater 145 had been disconnected via switch 165.

After cooling of the pedestal 143 and substrate 141, the tungsten hexafluoride gas is turned off via valve 167 to conserve gas and the pump 156 is inactivated. The overlay as deposited upon the substrate may then be removed from the chamber 144. During deposition the tungsten hexafluoride gas, which is corrosive is trapped in the cold trap 157 and thereby prevented from contaminating and damaging the pump 156. The system may be prepared for a second deposition by flushing with hydrogen gas as above described.

Surface irregularities on the emitting surface of overlay 142 are removed by polishing and preferably, for example, by electropolishing. In a typical example for tungsten the substrate 141 with the deposited tungsten overlay 142 is made the anode of an electrolytic cell. A suitable electrolyte is a 0.5% room temperature aqueous solution of sodium hydroxide. A voltage of six volts is applied between anode and cathode for a time sufficient to remove surface irregularities as of, for example, 5-10 minutes for overlay deposits of 0.0001-0.001" thick.

After electropolishing, the substrate 141 and overlay 142 are washed off with water followed by an acetone rinse. The emitters, thus fabricated, are then suitable for use in electron discharge devices.

The (210) crystal direction of tungsten is oriented normal to the emitting surface by the same method described above with regard to FIG. 20 except that the ratio of hydrogen to tungsten hexafluoride gas flow rates, instead of being 10 to 1 is 8 to 10. The H_2 flow rate can be changed and the WF_6 maintained constant to obtain this ratio.

The percent change in work function over the half width (2α) distribution is 2% for the aforementioned (100) and (210) grain oriented deposited emitting surfaces of tungsten as compared to a 10% change in work function over the typical patchy emitting surface.

The maximum size of the angular spread of the half width that can be tolerated for a certain uniformity of work function depends upon the rate of change of work function with crystal direction. The rate of change of work function varies widely as a function of crystal direction as can be inferred from FIG. 3.

An alternative deposition chamber for obtaining uniform polycrystalline grain oriented deposits on filamentary substrates is shown in FIG. 21. A hollow cylindrical envelope 171 as of glass contains a substrate filament 172 as of tungsten .006" in diameter and five inches long. The filament is coaxially disposed of the envelope 171 and held at its ends in tension via clamps 173. The substrate filament is heated to its deposition temperature as of 600° C. via direct current passing through the wire 172 at low voltage as of 6 volts obtained from battery 174 and controlled via variable resistor 175. Constituent vapor gas atmosphere is fed into chamber 171 via a glass input manifold 176 as of $\frac{3}{8}$ " diameter glass tubing with a plurality of $\frac{3}{8}$ " glass tubes 177 communicating between the manifold tube 176 and the chamber 171. A similar manifold exhausts the vapor atmosphere via tubes 178 and manifold tube 179. The deposition is rapidly terminated by opening the electrical heating circuit via

switch 181 which rapidly cools the filament 172 below the deposition temperature of 400° C. due to the low thermal mass of the filament 172.

In summary it has been shown that the emission characteristics of thermionic emitters, in general, will be improved by forming the emitting surface of a polycrystalline grain oriented material constituting the emitting surface. The grain oriented material may, in general, consist of any one of a number of different high melting point materials including elements and compounds.

The method of depositing grain oriented surfaces, as described above, forms the subject matter of and is claimed in copending continuation-in-part application 573,757, filed Aug. 18, 1966, and assigned to the same assignee as the present invention.

Suitable high melting point elements include the refractories such as tungsten, molybdenum, tantalum, niobium and rhenium. Other suitable high melting point elements include carbon, hafnium, iridium, osmium, platinum, rhodium, ruthenium, thorium, titanium, vanadium, yttrium, and zirconium.

What is claimed is:

1. A thermionic emitter adapted to operate at elevated temperature comprising, a body of high melting point material having at least one surface portion adapted to act as an electron emissive surface, and said electron emissive surface being constituted of a grain oriented polycrystalline material.

2. The apparatus according to claim 1 wherein said emitting surface is curved and the grain orientation constituting the emitting surface is maintained over the curved surface.

3. The apparatus according to claim 2 wherein said emitting surface is characterized by having substantially uniform emission properties over all microscopic portions thereof.

4. The apparatus according to claim 2 wherein said emitting surface has a substantially uniform work function over all microscopic portions thereof.

5. A thermionic emitter including, a structure of a high melting point material adapted to operate at elevated temperature, said structure having a surface portion adapted to act as an electron emissive surface, said emissive surface being constituted of the exposed ends of an ensemble of columnar crystallites, and a preponderance of said columnar crystallites being directed approximately normal to said emissive surface.

6. A thermionic emitter including, an emitter structure having an electron emissive surface adapted to provide copious electron emission at elevated temperature, and said emitting surface being a non-planar surface and having a uniform work function over the entire emitting surface.

7. The emitter of claim 6 wherein the work function of said emitter surface is uniform to 2% over the half width of the distribution function of the crystal direction constituting said emitting surface.

8. A thermionic emitter adapted to operate at elevated temperature comprising, an emitter structure having an emissive surface adapted to act as an electron emissive surface at elevated temperature, said emitting surface being constituted of a polycrystalline grain oriented material.

9. The emitter according to claim 8 including, a substrate base member, said polycrystalline material forming said emitting surface being overlayed upon said base member, and said polycrystalline material being selected from the group consisting of tungsten, molybdenum, tantalum, niobium, rhenium, carbon, hafnium, iridium, osmium, platinum, rhodium, ruthenium, thorium, titanium, vanadium, yttrium and zirconium.

10. The emitter according to claim 8 including a substrate base member, said polycrystalline material forming said emitting surface being overlayed upon said base member, and said polycrystalline overlay material being selected from the group consisting of rare earth oxides,

zirconium carbide, thorium carbide, uranium carbide, uranium nitride, lanthanum hexaboride, and neodymium hexaboride.

11. A thermionic emitter adapted to operate at elevated temperature comprising, a substrate member, an overlay of polycrystalline material disposed upon said substrate member, said overlay having an emissive surface, and said surface being constituted by an ensemble of grain oriented crystallites oriented with respect to said emitting surface such that said emitting surface is constituted of the crystallographic planes normal to the crystal direction of the oriented crystallites.

12. A thermionic emitter adapted for operation at elevated temperature comprising, a polycrystalline metallic substrate member, a polycrystalline overlay disposed upon said substrate member, said overlay having an emitting surface, and the crystallites of said overlay having an orientation with respect to said emitting surface which is substantially the same at all points with respect to said emitting surface whereby uniform emission is obtained from said emitting surface.

13. An electron discharge device including, a thermionic emitter structure adapted for operation at elevated temperature for emitting a stream of electrons, a collector electrode spaced from said emitter structure for collecting electrons from the electron stream, said emitter structure having an emitting surface for emitting the stream of electrons and being formed by a layer of grain oriented polycrystalline material.

14. The electron discharge device according to claim 13 wherein said electron discharge apparatus is a thermionic energy converter.

15. The electron discharge device according to claim 13 including, means for supplying a monolayer of coating material to said polycrystalline emitting surface, and said monolayer material having a lower work function than the bare emitting surface whereby the work function of said coated surface is lowered uniformly.

16. The device according to claim 13 including, anode means for drawing electrons from said emitting surface into an elongated stream, wave energy supporting means arranged along said stream in wave energy exchanging relationship thereto, and means for abstracting wave energy from said stream for propagation to a load.

17. The device according to claim 15 wherein, said crystallites constituting said emitting surface are grain oriented with the preferred crystal direction being the (111) direction, said polycrystalline coating material being tungsten, and said low work function coating material being selected from the group consisting of barium and thorium.

18. The device according to claim 15 wherein said means for supplying a monolayer coating material to said emitting surface is an electropositive ionized vapor atmosphere in equilibrium with said emitting surface for replenishing desorbed coating material.

19. The device according to claim 18 wherein said tube is a thermionic energy converter, said polycrystalline emitter material is tungsten, said emitting surface is curved, and said coating material is cesium.

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