

[54] **ELECTRODE FOR PULSE HIGH-
POWER ELECTROVACUUM DEVICES**

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abandoned.
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313/218, 313/330, 313/352, 313/355
[51] Int. Cl. **H01j 1/14, H01j 1/48**
[58] Field of Search.....313/218, 311, 330, 352, 355;
29/183.5, 198

[56] **References Cited**

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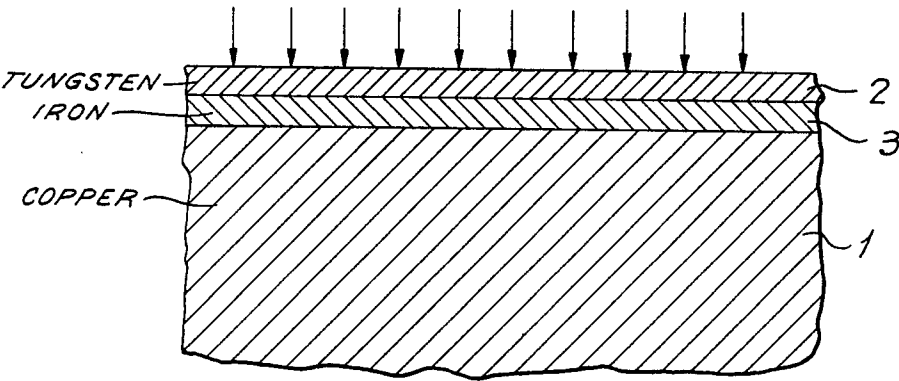
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[57] **ABSTRACT**

A copper electrode with a multi-layer coating wherein, for ex-
ample, the outer layer is of tungsten and the inner layer is of
iron, the outer layer functioning as a refractory material and
the inner layer being a transitional layer having thermal phys-
ical properties between those of the electrode and those of the
outer layer. Electrode with special coating to protect the same
against heat.

6 Claims, 6 Drawing Figures



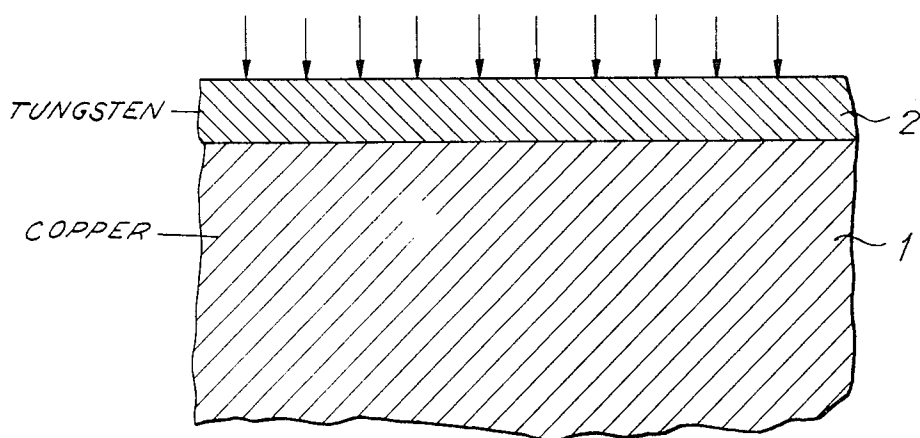


FIG. 1

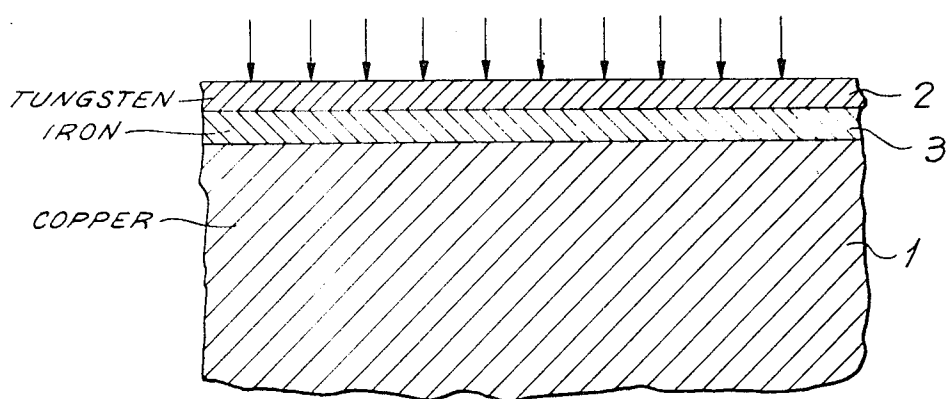
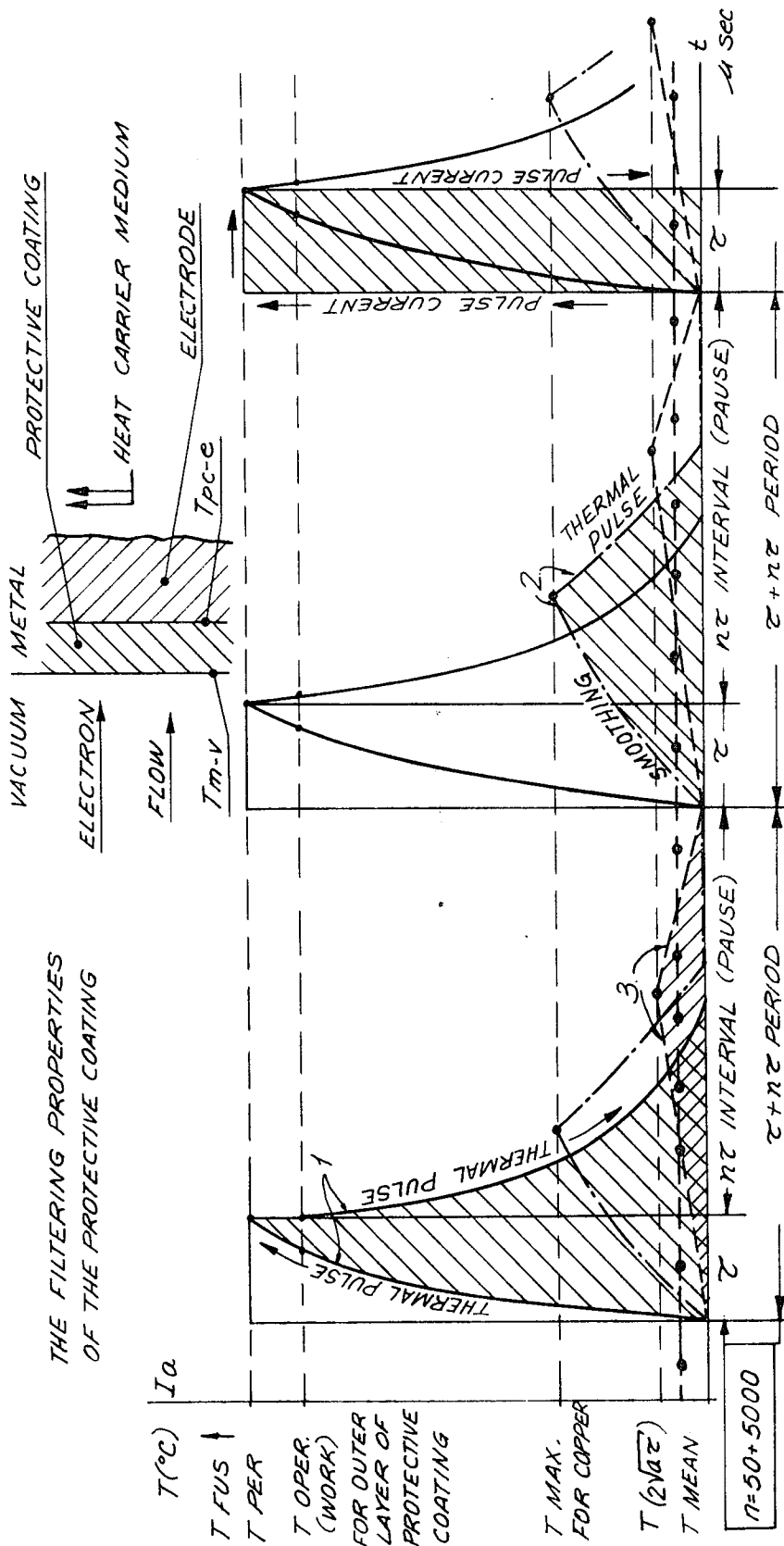


FIG. 2



- 1. - T_{m-v} - THE VALUE OF THE PULSE TEMPERATURE ON THE WORKING SURFACE OF THE ELECTRODE, i.e. ON THE BOUNDARY OF A METAL - VACUUM.
- 2. - T_{pc-e} - THE VALUE OF THE SMOOTHING PULSE TEMPERATURE ON THE BOUNDARY BETWEEN THE PROTECTIVE COATING AND THE ELECTRODE.
- 3. - $T(2\sqrt{a\tau})$ - THE VALUE OF THE SMOOTHING PULSE TEMPERATURE OF THE DEPTH OF THE ELECTRODE MATERIAL WHERE THE THERMAL PULSE PRACTICALLY DISAPPEARS.

FIG. 3

$T(2\sqrt{a\tau}) \approx \frac{1}{10} T \text{ PER } (2\sqrt{a\tau})$ - VALUE OF THERMAL SKIN-LAYER

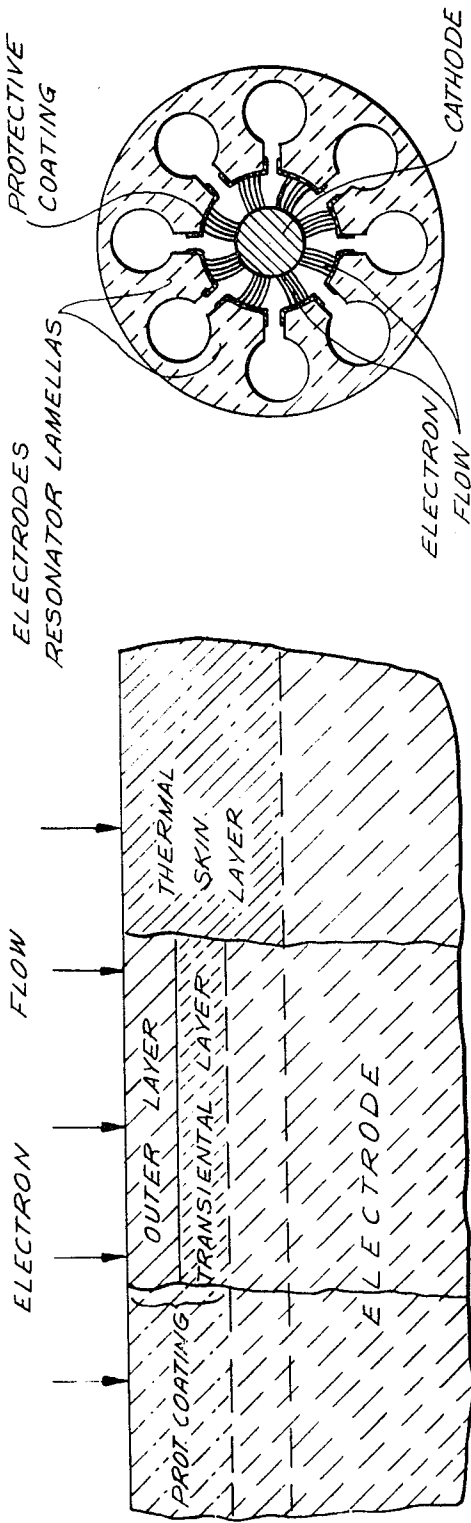


FIG. 5

MAGNETRON

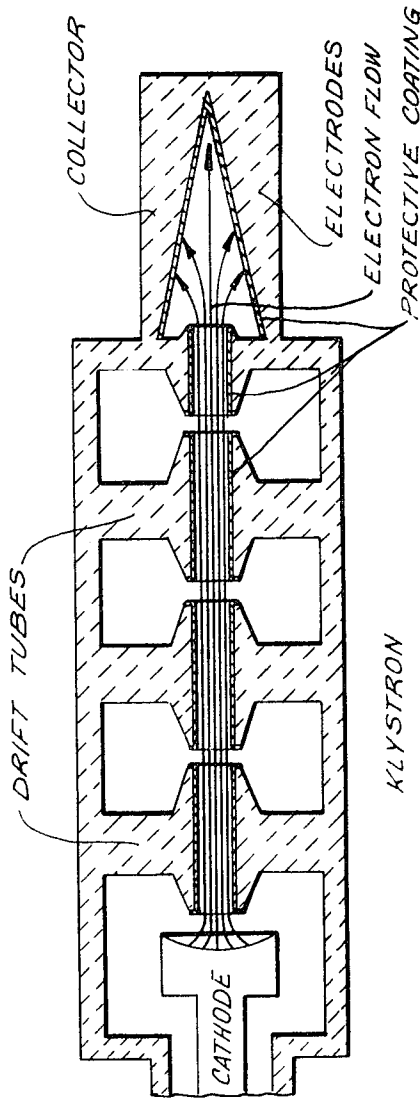


FIG. 6

KLYSTRON

ELECTRODE FOR PULSE HIGH-POWER ELECTROVACUUM DEVICES

This is a continuation of application Ser. No. 662,652 filed Aug. 23, 1967 and now abandoned.

DRAWING

FIG. 1 is a fragmentary longitudinal sectional view of a copper electrode with a layer of tungsten, in accordance with the invention;

FIG. 2 is a fragmentary longitudinal sectional view of a copper electrode with layers of iron and tungsten;

FIG. 3 is a chart explaining certain principles of the invention;

FIG. 4 is an explanatory diagram; and

FIGS. 5 and 6 show apparatus employing the invention.

DETAILED DESCRIPTION

The present invention relates to electrodes for impulse or continuous type electrical vacuum devices of high specific power, and more particularly to electrodes with special coating for preventing sublimation of a heat delivering electrode material during pulse or continuous operation.

Hitherto the problem of preventing the sublimation of electrode material has been accomplished by increasing the area to which electron flux is directed. Thus the specific values of thermal loads applied to a square centimeter of the electrode surface were kept below critical values and consequently the temperature, to which the electrode surface would be heated, was kept to a lower value than that permissible for a given material in vacuum.

It is well known that the electrodes of high-power electrovacuum super-high frequency apparatus, such as klystrons, magnetrons, and so forth, are manufactured from copper due to its high heat conductivity, impermeability and high mechanical properties. Not only copper, that is widely used at the present time in the electrovacuum industry, possesses such properties, but also other metals or alloys on the basis of copper, silver, gold, aluminum and other high heat conductivity metals.

The electrodes in modern high specific power pulse super-high frequency apparatus are designed in such a fashion that, although they can discharge the average power by means of a heat carrier, they cannot stand the pulse power resulting from the electron flux. During the time of the pulse, the temperature of the working surface of an electrode exceeds the permissible value. This is the so-called "surface thermal stroke." It can result in the melting of the electrode surface and a breakdown in the apparatus can be initiated by the sublimated material of the electrode.

Prior solutions of this problem were based on decreasing the specific pulse thermal loads applied to the unit electrode surface, i.e., by increasing the electrode working surface. A shortcoming of such solutions was an unjustified increase in overall dimensions and weight of the electrodes and of the whole apparatus as well as poor average or mean power discharge. These aspects are particularly important for super-high frequency pulse apparatus (in the millimeter and centimeter range), the design features and operating conditions of which often require minimization of the dimensions of electrodes bombarded by the electron beam.

The necessity to create electrovacuum devices for high specific powers requires a radically new solution of the problem.

I am aware that prior to my invention some particular designs were known, such as small plates of refractory metals soldered into copper anodes of X-ray tubes functioning as a mirror. Such a technique was, however, intended to provide an anode mirror which would be made of a material with a high atomic number, determining the intensity of mixed radiation, the efficiency of the tube and the frequency of the Roentgen spectrum characteristic radiation.

Attempts have been made to manufacture collectors for traveling-wave tubes from molybdenum or to design resonator

systems for magnetrons by silver soldering molybdenum lamina into a copper base. None of these attempts has been successful.

First of all, the low heat conductivity of molybdenum, as compared with that of copper, makes it impossible to deliver considerable amounts of average power with the help of electrodes made wholly or partially from molybdenum.

Secondly, owing only to the thermophysical properties of molybdenum, the value of the thermal stroke upon the electrode surface is three times as high as the thermal stroke when a copper electrode is used. In this case, the rise of the temperature of the electrode can be with great difficulty be compensated by the higher temperature which is permissible for heating molybdenum in vacuum without a marked sublimation.

Thirdly, due to the difficulties involved in obtaining prefabricated molybdenum parts of large dimensions and their subsequent machining, it is almost impossible to manufacture electrodes of any shape and size from this metal.

Hence, the above-mentioned designs of electrodes are not universal and they do not considerably increase the dissipated pulse and continuous power over that permitted by the use of copper electrodes.

This is why my invention is not limited to designs of electrodes which are applicable only in some particular cases for a narrow class of electrovacuum apparatus. Instead, my invention relates to a general-purpose design of an electrode for electrovacuum devices of high specific power, which is free of the shortcomings mentioned above and permits increasing by several times the specific pulse and specific continuous thermal loads which can be applied to such electrodes.

The invention can be employed when it is necessary to increase the thermal load in an electrovacuum device, created by the electron flux per unit of the electrode surface, for instance in all kinds of super-high frequency apparatus for pulse or continuous operation, electron accelerators, dischargers and other electrovacuum pulse devices.

A main object of the present invention is to prevent sublimation of the heat-delivering material of the electrodes in electrovacuum devices of high specific power, said sublimation being the result of thermal overloads exceeding that permissible for the particular material in vacuum.

Another object of the present invention is to increase by several times the permissible pulse and continuous power, dissipated by the electrodes of powerful electrovacuum devices, without causing any damage to their working surface and to the vacuum in the device.

Yet another object of this invention is to prolong the service life of such devices.

Among other objects of the invention is the possibility to reduce considerably, when necessary, the overall dimensions of a device without changing its power.

The preferred embodiment of the present invention is an electrode of the required shape and overall dimensions, made from a material with a high heat conductivity, on the working surface of which a thin layer of refractory metal is applied characterized both by the highest permissible temperature of heating in a vacuum and by the maximum values of heat conductivity and heat capacity. The thickness of such a layer is determined by the thermophysical properties of the layer material, as well as by the pulse power per unit of the electrode surface, the duration of the pulse and the supply voltage for the device. This thickness is calculated for each particular case in accordance with these parameters.

The preferred embodiment is a copper electrode coated with a layer of tungsten.

The nature of this invention becomes apparent when it is taken into account that copper, owing to its high heat conductivity, is a perfect conductor of a steady heat flow. The layer of refractory metal, the permissible temperature of which is many times higher than the temperature for the copper, can perfectly withstand thermal overloads during the current pulse and continuous operation. During the interval between pulses,

this layer should equalize the temperature in such a way as to allow only the weak and smooth temperature changes in the range permissible for the copper to reach the copper subplate. Hence, the layer of refractory metal acts in such a case as a thermal ripple filter, converting the pulse heat flow into a more or less steady flow, which can be transmitted to a heat carrier through the copper subplate which is in proper thermal contact with the layer.

In continuous operation the thermal resistance of the protection coating made of refractory metals and having a thickness of a few microns is negligibly small (1 to 0.1 percent) as compared with the thermal resistance of an electrode made of higher heat-conducting metals, but having a thickness of several millimeters. The temperatures drop across the protection coating may be neglected.

Another embodiment of the present invention contemplates a copper electrode, whose working surface is coated with several layers of various refractory metals, the metals of the intermediate layers possibly having a lower permissible temperature than the metal of the external layer. In this case, the thermophysical properties of the intermediate layers should be close to those of copper.

The nature of the invention will be understood from the following description of its embodiments in the accompanying drawings.

Referring now to FIG. 1, an electrode is shown comprising a copper subplate 1 coated with a tungsten layer 2. Layer 2 can also be made of tantalum, rhenium, niobium or molybdenum, and the sulphate 1 of any high heat conductivity metal.

Such an electrode withstands surface thermal strokes, created by a pulse flow of electrons (shown in FIGS. 1 and 2 by arrows) with a specific power of several hundred kW per square centimeter during several hundred microseconds. At 100 kV the depth of electron penetration into the tungsten layer does not exceed 10 μ (microns) and the thickness of the heat skin-layer is approximately 200 μ for tungsten and 400 μ for copper. The thickness of the protection coating, in such particular case, is 100 to 120 microns.

For continuous operation the thickness of the protection coating must be so small that the thermal resistance of the protection coating be negligible compared with the thermal resistance of the electrode 1; however, this value must also be adequate for the protection coating to be continuous and strongly adhering to the electrode 1, so as not to allow the passage of metal gases and vapors emitted from the electrode 1 at thermal loads several times exceeding those usually permissible for an electrode having no protection coating.

FIG. 2 shows an electrode comprising a copper subplate 1 coated with iron layer 3 the heat conductivity of which is close to that of copper, but the permissible temperature of heating of which in a vacuum is higher than that of copper. Layer 3 can also be gold, nickel, titanium, platinum or rhodium. Said transitional layer can be formed by treating the material of the base with ions of refractory material.

The iron layer 3 is in turn coated with tungsten layer 2 (or a metal as stated above) having a high permissible temperature of heating in a vacuum. In realizing the invention, application of a thin layer of refractory metal as well as coating with a combination of refractory metal layers can be effected using the following conventional methods:

1. plasma spraying of refractory metal;
2. evaporation of metals in a vacuum by means of electron bombardment;
3. cathode spraying;
4. application of refractory metals by precipitation from a gaseous phase;
5. electrolytic coating with refractory metals from electrolyte melts.

In the practical application of the invention, one of the methods may be chosen depending on the shape and overall dimensions of the electrodes and on the equipment available. Any of these methods can provide for more fine-grained and denser layers of refractory metals than metal layers obtained

by the method of powder metallurgy, as well as for layers with sufficiently good adhesion to the basic metal of the electrode.

It has been established that the electrode according to the invention for electrovacuum devices high specific power can be manufactured with the use of simple technological methods and that this electrode provides for a considerable reduction in expenditure of materials and labor per unit of power of the commercially produced electrovacuum devices. The term "skin-effect" effect which is well known in electron tube design signifies the surface effect observable in a uniform medium under the action of some external factors causing non-uniform distribution of some physical properties resulting in that a thin outer (surface) layer of such medium acquires properties different from those of the medium as a whole.

Such thin surface layer of the substance, in which the "skin-effect" is observable, is called the "skin-layer."

Known in technology, are high-frequency, magnetic and other skin-effects. Thus, in the field of high-frequency electrovacuum devices, to which the invention relates, a "high-frequency skin-effect" is known, i.e., a phenomenon of non-uniform distributing of the high-frequency current along the cross-sectional area of the electrode, the current density at the surface being maximum and decreasing further away from the surface into the depth of the electrode.

I have studied the phenomenon of braking the heat pulse caused by the current pulse in the electrode material, due to that the heat pulse maximum is highest at the surface and decreases further away from the surface into the depth of the electrode material, decreasing of the heat pulse maximum value being accompanied by an increase of the heat pulse duration so that at some depth of the electrode material the heat pulse practically vanishes (decays), while the energy carried by the repeating heat pulses acquires the character of a continuous heat flow. Such phenomenon of braking, by analogy with the high-frequency skin-effect, is called the "heat skin-effect." While the value $2\sqrt{a\tau}$ equal to the electrode layer material thickness, along the depth of which the heat pulse practically vanishes, is called the "heat-skin layer".

As stated above, the protective coating thickness is to be calculated in each individual case for each particular pulse device, depending on the combination of the parameters of the device. It follows that this thickness may vary within some limits. The formulae for such calculations are cumbersome and I therefore define the thickness of the protective coating as a "thin film" or "thin layer," whose thickness is proportional to the value of the "heat skin-layer."

The term "heat skin-layer" should be understood as the value defining (characterizing) the electrode substance layer thickness along the depth of that the heat pulse practically vanishes, i.e., decreases at least 10 times. The heat skin-layer is a mathematical value depending on the thermophysical properties of the material (or materials) in which the heat pulse propagates, and also on the current pulse duration. By means of this value, it is convenient to define or characterize the protective coating thickness over the entire range of variation of the principal parameter of the pulse device, i.e., the current pulse duration τ .

The protective coating is composed of real layers of various metals specially selected having definite thicknesses depending on the parameters of the device. The object of the protective coating is to reduce several times (not more than 10 times) the value of the pulse temperature on the border coating-electrode, as compared with the pulse temperature appearing on the border metal-vacuum.

The heat skin-layer is a mathematical value depending on the thermophysical properties of the material (or materials) in which the heat pulse propagates, and also on the current pulse duration. By means of this value, it is convenient to define or characterize the protective coating thickness over the entire range of variation of the principal parameter of the pulse device, i.e., the current pulse duration τ .

Choosing the factor of proportionality between the protective coating thickness and the value of the heat skin-layer is a

matter for the engineer who designs the particular device. The figures for this factor (0.4–0.7) may be given as an example.

FIG. 3 shows curves illustrating the filtering properties of the protective coating. Reference to these filtering properties has been made hereinabove. FIG. 4 shows the location of the protective coating, the outer and transitional layers, also the heat skin-layer under the working surface of the electrode. FIGS. 5 and 6 show a schematic arrangement of a magnetron and a klystron indicating the points where protective coatings may be used.

As to the thermophysical properties, the most important among them are: λ —heat conductance, c —heat capacity, γ —density, α —linear expansion factor, a —temperature conductance, ϵ —heat activity factor, T_{fusion} —fusion temperature, T_{boil} —boiling temperature, T_{per} —heating in vacuum permissible temperature. In choosing the metal for the protective coating outer and transitional layers, the designer must be guided by the combination of the above thermophysical properties. It should be noted that obtaining a transitional layer to insure more dependable adhesion, and thus also thermal contact between the outer layer and the electrode material is one of the objects of the invention.

The thickness of the protective coating is not more than that of the heat skin-layer, but adequate to have a smoothening effect on the heat pulses to convert them into heat continuous power at a lower temperature so that it can be resisted by the electrode which has a sufficiently high heat conductance to conduct away the average heat power. At the same time this value must be so small as not to have any appreciable effect on the total heat—and electric conductance of the electrode as a whole. The said protective coating consists of an outer layer of a pure refractive metal and a transitional layer, whose thermophysical properties are intermediate between the thermophysical properties of the electrode main material and the refractory metal of the protective coating outer layer, and gradually smoothly vary from the values characterizing the electrode material to the values characterizing the metal of the protective coating outer layer. Such coating increases by several times the resistibility of the electrode to pulse electron bombardment.

The range of application of the protection coating consisting of outer layer 2 and transition layer 3, as already stated, is by no means restricted to electrovacuum pulse devices of high specific power only. The said coating can also be effectively used in electrovacuum devices operating under continuous conditions. The protection coating would permit to increase by several times the specific thermal load on the electrode, and thus to raise the efficiency of heat-removal (cooling) systems that have gained considerable use recently.

Modern high-efficiency cooling systems of powerful electrovacuum devices permit, under continuous conditions of operation, to conduct away from the operating surface of the electrode to a heat-carrying agent considerable heat flows caused by specific loads of several kilowatts per square centimeter of the electrode operating surface.

Such cooling systems are those with boiling heat-carrying agents. There are two varieties of such systems. In systems of the "Vapatron" type, boiling of the heat-carrying agent, that is in a state of stable mixed (bubble and film) boiling, proceeds at atmospheric pressure with steam condensation in suitable devices. A characteristic feature of such systems are thick-walled electrodes with massive ribs of various configuration.

The other system makes use of surface bubble boiling with steam condensation in the center of the heat-carrying agent flow where the boiling temperature is not reached. This system uses forced driving of the heat-carrying agent at high velocities (above 10 m/sec.) and high pressures (above 10 atm.) along channels of small sectional area.

The limiting factor in the use of the said systems is the low permissible temperature of the electrode operating surface that is bombarded by the electron flow.

It has now been experimentally established that the protection coating described above, having a thickness of a few (1 to

10) microns, possessing good adhesion to the electrode material and free of pores or cracks, permits to raise the heating temperature, permissible at conditions of continuous operation, in vacuum, from 300°–400° C. to 900°–1,000° C. It is thus possible to increase several (about 3) times the heat flow transmitted from the loaded (operating) electrode surface to the surface washed by the heat-carrying agent.

It can thus be said that the protection coating does not increase the heat resistance of the electrode, but protects the overheated areas of the electrode against sublimation both under pulse and continuous operation conditions in high-power electrovacuum devices at thermal loads that are several times higher than those permissible for an electrode having no protection coating. As a result of the use of a protection coating, it is possible to obtain an electrode possessing thermal stability proper to the said refractory metals, without any reduction in the thermal conductance of the basic material of the electrode 1.

The only difference between protection coatings for pulse conditions and those for continuous operation conditions consists in their respective thicknesses. For continuous operation conditions, the thickness of the protection coating is naturally constant and is in no relation with the thermal skin-layer, since such a conception in the case of continuous operation conditions does not exist. Such coating may have a thickness of a few microns. However, it must possess maximum possible thermal contact with the electrode, minimum thermal resistance, and be free of pores or cracks.

Though the present invention is described in connection with only two embodiments, various changes and modifications can be made without departing from the spirit and scope of the invention as those skilled in the art will easily understand. Such changes and modifications are considered to fall within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. An article of manufacture comprising an electrode and a multi-layer coating on said electrode for protecting the same against effects of erosion and gas emission, caused by electron bombardment, in an electro-vacuum device operating on pulse duty, said coating comprising an outer layer of a material possessing a high permissible temperature of heating in vacuum for allowing said outer layer to withstand a pulse thermal load several times as high as the maximum load that would be permissible for an electrode having no protective coating, a transitional layer located between the outer layer and the electrode to ensure dependable bonding and effective thermal contact between the outer layer and the electrode, the transitional layer possessing thermophysical properties gradually varying in the range of values between such properties of the electrode and such properties of the outer layer, said protective coating being comparatively thin so that its thermal resistance to a constant thermal flow is minimal in comparison with the thermal resistance of an electrode having no coating, the thickness of the protective coating being not more than that of the thermal skin-layer, but sufficient to provide a smoothening effect on the thermal pulses and to transform them into a constant thermal power at a lower temperature at which such power can be dealt with the electrode with a thermal conductivity sufficiently high to be able to transfer the mean thermal power.

2. An article as claimed in claim 1, wherein said outer layer consists of at least one refractory metal selected from the group consisting of tungsten, tantalum, niobium, rhenium, rhodium, molybdenum, and said transitional layer consists of at least one metal selected from the group consisting of gold, nickel, iron, titanium, and platinum, the thickness of the protective coating being not more than that of the thermal skin-layer.

3. An article as claimed in claim 1, wherein said outer layer consists of at least one refractory metal selected from the group consisting of tungsten, tantalum, niobium, rhenium, rhodium and molybdenum and having a high permissible tem-

perature of heating in a vacuum such as to allow said outer layer to withstand a pulse thermal load that would be permissible for a copper electrode having no protective coating, said electrode being of copper, said transitional layer consisting of a surface layer of copper on the copper electrode and ions of the refractory metal of which the outer layer consists.

4. A multilayer coating for protecting an electrode against effects or erosion and gas emission caused by electron bombardment in an electrovacuum device operating on continuous duty, said coating comprising an outer layer of a material having a high permissible temperature of heating in vacuum to allow said outer layer to withstand a continuous thermal load several times as high as the maximum load that would be permissible for an electrode having no protective coating, and a transitional layer located between said outer layer and the electrode to insure dependable bonding and effective thermal contact between the outer layer and the electrode, the transitional layer having thermo-physical properties gradually varying in the range of values between the same properties of the electrode and the same properties of the outer layer, said protective coating being comparatively thin so that its thermal resistance to a constant thermal flow is minimal in comparison with the thermal resistance of an electrode having a thermal conductivity sufficiently high to be able to transfer a considerable continuous thermal power, but sufficiently thick and

solid to be free of pores or cracks and to be able to prevent emission of metal vapors and gases from the working surface of the electrode at constant temperatures several times as high as the maximum temperature permissible for heating in a vacuum of an electrode having no protective coating, the thickness of the said coating not exceeding ten microns.

5. A multilayer coating as claimed in claim 4, wherein the outer layer consists of at least one refractory metal selected from the group consisting of tungsten, tantalum, niobium, rhenium, rhodium and molybdenum, said transitional layer comprises at least one metal selected from the group consisting of gold, nickel, iron, titanium and platinum, the thickness of the said coating not exceeding 10 microns.

6. A multilayer coating as claimed in claim 4, wherein said outer layer consists of at least one refractory metal selected from the group consisting of tungsten, tantalum, niobium, rhenium, rhodium and molybdenum and having a high permissible temperature of heating in a vacuum such as to allow said outer layer to withstand a continuous thermal load that would be permissible for a copper electrode having no protective coating, said electrode being of copper, said transitional layer comprising a surface layer of copper on the electrode and ions of the refractory metal of which the outer layer consists.

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