

June 18, 1940.

V. K. ZWORYKIN ET AL
ELECTRIC DISCHARGE DEVICE

2,205,055

Filed April 30, 1936

2 Sheets-Sheet 1

Fig. 1.

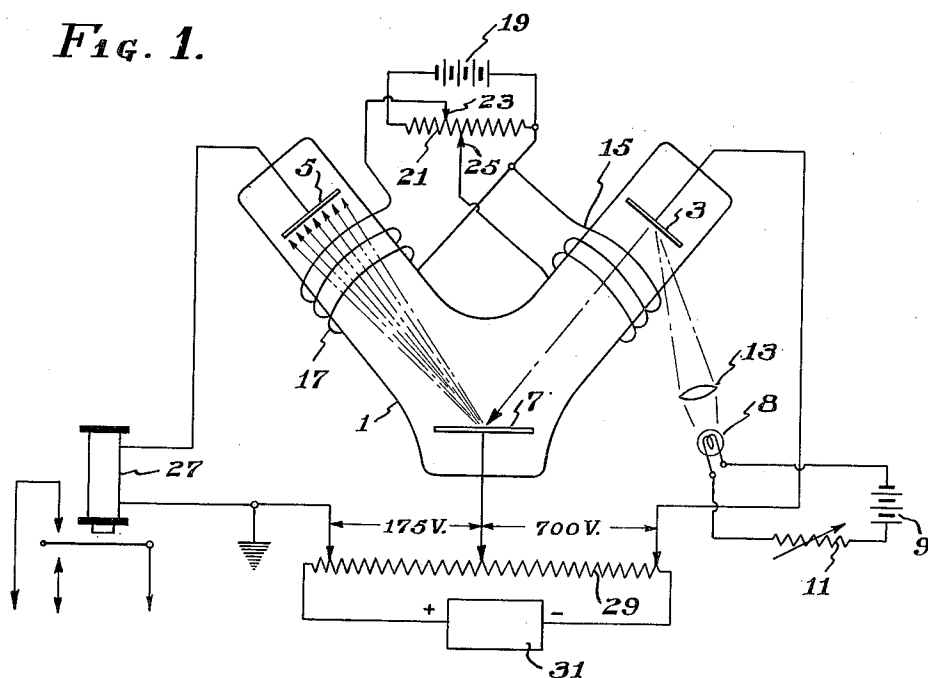
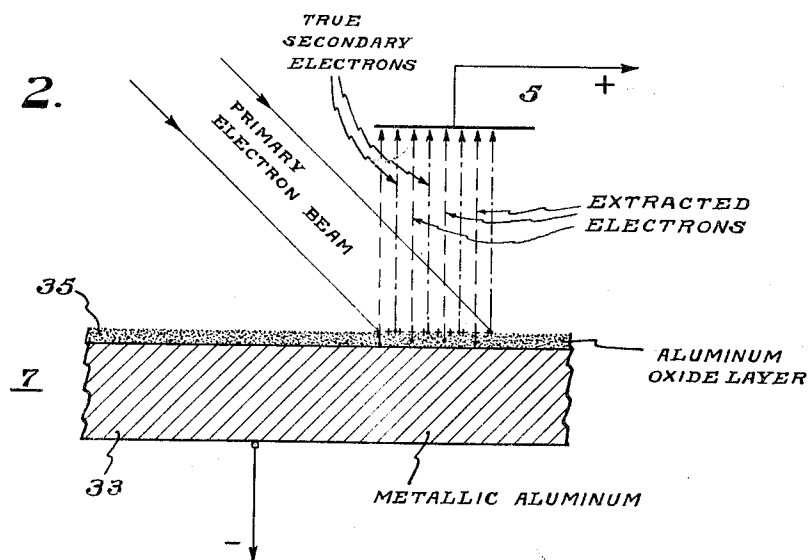


Fig. 2.



INVENTORS
Vladimir K. Zworykin
Louis Malter

BY *JR Goldsborough*
ATTORNEY

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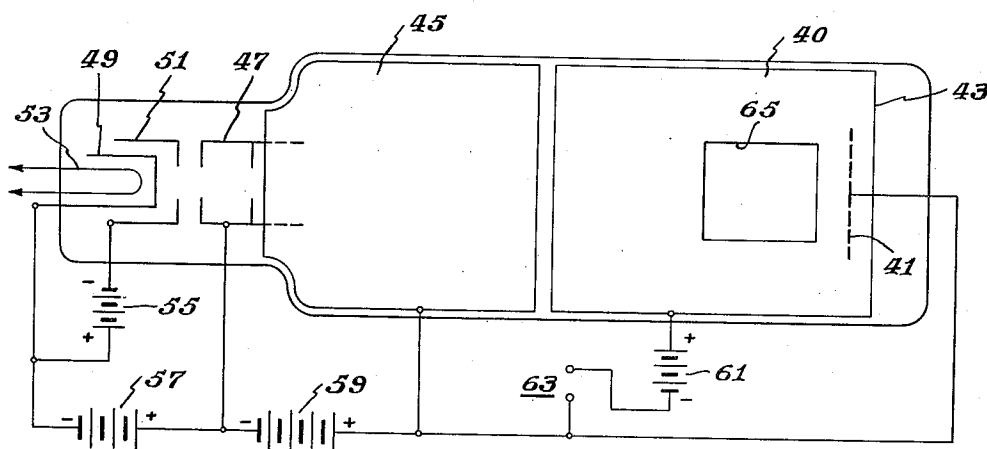
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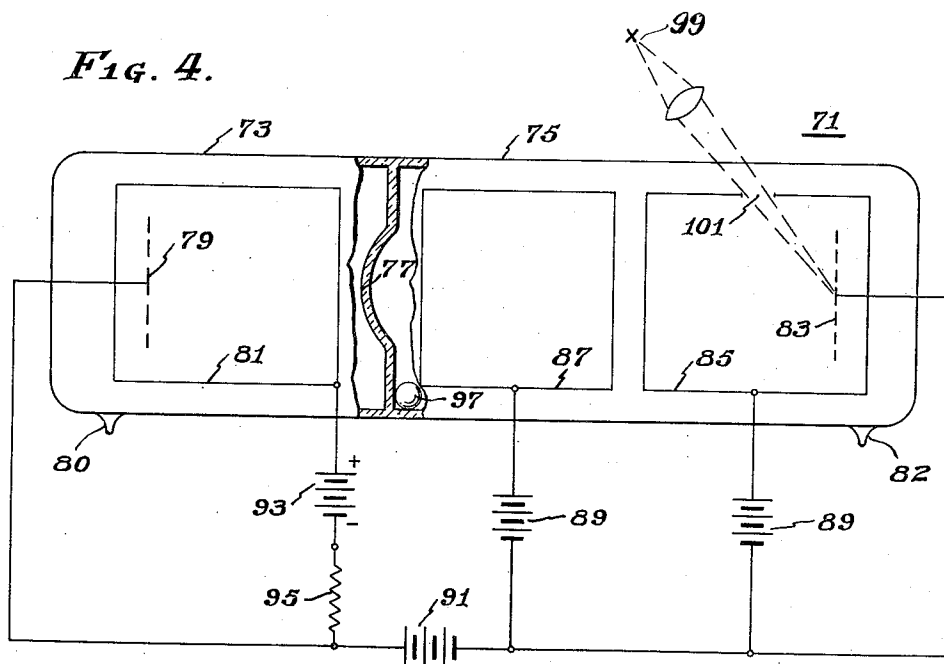
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2 Sheets-Sheet 2

F1 G. 3.



F'ig. 4.



Inventors
Vladimir K. Zworykin
Louis Malter

 $\mathfrak{B}_y$

Louis M.
Gust

Attorney

UNITED STATES PATENT OFFICE

2,205,055

ELECTRIC DISCHARGE DEVICE

Vladimir K. Zworykin, Philadelphia, Pa., and
Louis Malter, Collingswood, N. J., assignors to
Radio Corporation of America, a corporation of
Delaware

Application April 30, 1936, Serial No. 77,092

14 Claims. (Cl. 250—27.5)

This application is a continuation in part of the copending application of Vladimir K. Zworykin and Louis Malter, Serial No. 39,368, filed September 6, 1935, for an improvement in Electron discharge devices.

Our invention relates to electric discharge devices and it has particular relation to electrodes, capable of secondary emission, for use therein.

By way of example, our improved electrode is of great value in devices of the type exemplified by the Slepian Patent No. 1,450,265. In the patent referred to there is disclosed a thermionic source of electrons, means for subjecting emitted electrons to an electrostatic field, electromagnetic means for deflecting the emitted electrons to an electrode which emits secondary electrons under electron impact, together with an additional electrode for collecting the secondary electrons.

A number of metals are suitable for use as the material from which the secondary emitting electrode may be made and for this purpose perhaps the best material hitherto known is silver, which has been oxidized and then sensitized by the formation thereon of a layer of caesium oxide. Caesiated silver, however, does not appear to be capable of emitting more than approximately nine secondary electrons for each impinging primary electron and, consequently, if copious secondary emission is desired, it has been found necessary to utilize a large number of secondary emitting electrodes in cascade. Such an arrangement is quite well exemplified by French Patent No. 582,428, which discloses an "electron multiplier" comprising three secondary electron emitting electrodes.

It is, accordingly, an object of our invention to provide an electrode material that is capable of emitting many more electrons per impinging electron than materials heretofore known.

In accordance with our invention, we provide a conducting electrode with a very thin insulating layer or film and so sensitize the surface of the layer that its capability of emitting true secondary electrons when under electron impact is increased. As the electrode material we prefer aluminum. The insulating layer may be electrolytically formed aluminum oxide and the sensitizing is accomplished by depositing a monatomically thin layer of alkali metal upon the oxide, which layer is thereafter oxidized.

In utilizing our improved electrode, we subject the surface to a stream of electrons to thereby cause the emission of true secondary electrons and the consequent building up of a high positive charge on the oxide layer. By associating a

collector electrode with the coated electrode, and by maintaining the collector electrode highly positive with respect thereto, electrons drawn from the collector electrode by the surface charge may be utilized in an output circuit.

The novel features which we consider characteristic of our invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in connection with the accompanying drawings, in which

Fig. 1 is a diagrammatic view of an electron multiplier system wherein an electrode constructed according to our invention may advantageously be utilized,

Fig. 2 is a diagrammatic view to which reference will be made in explaining the theory which at present we believe to account for the copious electron emission from an electrode surface formed according to our invention,

Fig. 3 is a schematic illustration of a modified form of electron multiplier utilizing an electrode constructed in accordance with our invention, and

Fig. 4 is a schematic diagram of another embodiment of our invention.

Referring now to Fig. 1 of the drawings, an electron multiplier in which an electrode formed according to our invention can be utilized may comprise a Y-shape evacuated container 1 within which, adjacent to the extreme end of one of the arms, is mounted a photosensitive cathode 3 and within the end of the other arm of which is mounted an output electrode 5. The cathode material may be silver, having a surface layer comprising caesium oxide.

An electrode 7 capable of emitting secondary electrons is disposed within the stem of the container in such position that it is accessible to electrons emitted from the photosensitive cathode 3 and is also visible from the output electrode 5. For purposes of convenience the electrode mounted in the stem of the container will be referred to as a "multiplying electrode."

A variable or a constant light source may be so disposed with respect to the container that light therefrom falls upon the photosensitive cathode. In the drawings, such light source is exemplified by a light 8 connected in circuit with a battery 9 and a variable rheostat 11, and a lens 13.

Under the influence of light from the source, 55

electrons leave the surface of the photosensitive cathode in random directions. Since it is desirable to focus all such electrons upon the multiplying electrode an electromagnetic coil 15 may be disposed around one arm of the container between the photosensitive cathode and the multiplying electrode. A similar coil 17 may be disposed around the other arm of the container for the purpose of focusing secondary electrons upon the output electrode.

The several focusing coils may be provided with unidirectional potential from a battery 19 or the like. In the drawings these coils are exemplified as being connected in parallel to the battery, a potential divider 21 and a plurality of contact devices 23 and 25 being utilized for the purpose of individually controlling the magnitude of the several focusing field currents. It is our understanding that the polarity of the coils is immaterial. Alternatively, electrostatic focusing of the electrons may be resorted to, or a combination of electrostatic and magnetic focusing.

In the operation of an electron multiplier of the type under discussion the output electrode 5 may be connected to any suitable utilization circuit, such as a relay 27. When utilizing a multiplier of the type shown, the photosensitive cathode may be connected to the negative terminal of a potential divider 29 that is connected across a source of unidirectional potential, 31, the output electrode 5 connected to the positive terminal of the potential divider and the multiplying electrode 7 connected to an intermediate point thereon. The relative potentials shown in the drawings are to be construed solely as illustrative.

In accordance with our invention, referring to Fig. 2 the multiplying electrode is made from a sheet of aluminum 33 which carries a layer or film 35 of aluminum oxide formed electrolytically in a saturated solution of borax and boric acid or the like. We have utilized layers varying in thickness from 10^{-7} centimeters to $3(10^{-5})$ centimeters. Thus far, our best results have been obtained with a thickness of 10^{-7} centimeters.

In manufacturing a device of the type shown, after the oxidized aluminum electrode and the other electrodes are mounted in place, the tube is highly exhausted and a slight amount of alkali metal, such as sodium, potassium or caesium is distilled into it. Caesium is preferred. Only sufficient alkali metal is used to form a molecularly thin coating upon the aluminum oxide and to sensitize the cathode. The coating is probably discontinuous and it may be that it consists of spaced apart molecules of the metal, insulated by aluminum oxide from each other and from the underlying metallic aluminum. At least, the coating is sub-microscopic and it is hardly possible to do more than theorize about its exact character.

It may also be possible that the caesium interpenetrates the oxide layer to some extent. The terms "layer," "film," "surface coating" and the like, therefore, where hereinafter used, are not to be construed as necessarily implying physical continuity, and homogeneity but are to be given as broad an interpretation as is consistent with our disclosure. Obviously, the sub-microscopic thickness of the alkali metal oxide precludes exact determination of their character.

The tube, after the introduction of the alkali metal, is preferably baked at 200° C. for approximately ten minutes and then permitting it to cool to room temperature. Subsequent to cooling, pure oxygen is admitted into the tube to react

with the caesium and is permitted to remain therein for a short time. The tube is then re-evacuated to a pressure sufficiently low to prevent ionization during use. Presumably, the alkali metal which deposits upon the aluminum oxide layer is also oxidized and the ability of the electrode to emit true secondary electrons is thereby enhanced. It is to be borne in mind, however, that the baking of the oxidized aluminum electrode and the introduction of oxygen, even without the introduction of the alkali metal, gives rise to a surface which is vastly more efficient than surfaces known to the prior art although it is not so efficient as the surface consisting of an oxidized alkali metal on aluminum oxide.

From the foregoing, it might be inferred that each electrode must be separately treated in the tube in which it is to be utilized. Such is not the case, however, since we have found it quite feasible to oxidize and sensitize aluminum sheets, following the process described and, thereafter, to cut the sheet into a number of electrodes.

We are not at this time prepared to formulate an exact theory of operation of our improved electrode material. We are, however, under the present impression that the copious electron emission therefrom is the result of secondary emission, as it is ordinarily understood, and also of the emission of electrons from the surface of the metallic aluminum and the aluminum oxide under the influence of electrostatic forces developed by the surface charge which the layer acquires.

That is to say, we believe that when primary electrons, strike the treated surface they release a certain number of true secondary electrons. These electrons are drawn over to the output electrode 5 leaving a positive charge upon the aluminum oxide layer. By reason of the high resistance of the aluminum oxide film, this positive charge does not disappear rapidly. If the primary beam is permitted to fall upon the surface for an appreciable length of time, the positive charge upon it becomes so great as to cause the extraction of an extremely large number of additional electrons from both the aluminum oxide and the underlying aluminum.

On the basis of this theory, it is possible to explain the various manifestations of this phenomenon. Thus:

(1) After the primary electron beam is turned on, an appreciable time must elapse before the electron emission reaches its highest value. This, we believe, is because the surface positive charge must first be built up.

(2) After the primary beam is cut off, the emission persists. This is probably because the high resistance of the oxide film prevents the positive charge from being neutralized rapidly. It should be pointed out here that apparently the extracted electrons can not contribute to a great extent to the neutralization of the surface positive charge. Probably the electrons shoot right by the surface positive charge in the same manner as they do through the grid of a radio vacuum tube.

(3) An increase in the collector voltage causes a rapid increase in the extracted electron current. This may be attributed to the fact that the higher the collector potential, the higher is the potential to which the surface charge can build up and, as a consequence, the higher the extracted electron emission.

(4) If light is permitted to shine upon the surface while the electron beam is also impinging

upon it, the extracted electron emission decreases. This is believed to be caused by a decrease in the resistivity of the aluminum oxide film, with a consequent decrease in the surface charge. This is a purely ad hoc hypothesis which has not been checked experimentally. Light shining upon the surface after the beam has been cut off causes a more rapid decay of the emission. This is also explained by photo conductivity of the aluminum oxide film. If the electron beam is cut off and the collector circuit opened at any time thereafter for an instant, it is found upon reclosing the circuit that the extracted emission has decreased to almost zero, whereas if the circuit had not been opened, the emission would still have its large persistent value. Apparently, the opening of the circuit, with consequent removal of the collector potential, causes the electrons which would ordinarily be shot through the surface positive charge into the external space, to go to the surface positive charge and neutralize it.

The persistence of the extracted electron emission after the removal of the primary beam has been detected after 24 hours. The highest ratio of extracted electron current to primary beam current yet detected is in the neighborhood of 3000.

It should be clear now, on the basis of the foregoing description, why the introduction of caesium together with its subsequent oxidation causes a greatly enhanced extracted electron emission over that obtained from the untreated aluminum oxide surface. The true secondary emission from the oxidized caesium layer on the aluminum oxide is undoubtedly much higher than that from the pure aluminum oxide surface. As a consequence, under the action of an impinging electron beam, the caesiated surface is charged to a higher positive potential than when it is uncaesiated, resulting in a more copious extracted electron emission.

In Fig. 3 another embodiment of the multiplying electrode of our invention is illustrated. Within an evacuated envelope 40 are mounted a secondary emissive electrode 41, an output electrode 43, focusing electrodes 45, 47, a unipotential cathode, or electron gun 49 and a grid 51. The electron gun 49 is energized by a heater 53 which is connected to any suitable power source (not illustrated). A biasing battery 55, polarized as shown, is connected between the electron gun and grid.

The first focusing electrode 47 is connected to the positive terminal of battery 57. The negative terminal of this battery is connected to the electron gun 49. The second focusing electrode 45 is connected to the positive terminal of biasing battery 59. The negative terminal of this battery is connected to the first focusing electrode 47. The positive terminal of the biasing battery 59 is connected to the secondary emissive electrode 41. The output electrode 43 is connected to the positive terminal of a biasing battery 61. The negative terminal of this battery is connected to one of the pair of output terminals 63. The other of these terminals is connected to the emissive electrode 41. The output or load circuit (not shown) is connected to the output terminals 63.

The focusing electrode 45 and the output electrode 43 may be any suitable type. By way of example, we have found a platinum film, which is applied to the inner surface of the envelope 40, makes a satisfactory electrode. A window 65 may be included in the output electrode 43.

Through this window, the effects of primary electrons impinging on the emissive electrode may be viewed. These effects are made evident by a faint blue fluorescence on the oxide surface of the emissive electrode, or scintillations which accompany increasing the voltage and current beyond certain limits.

In the embodiment of our invention illustrated by Fig. 3, the primary source of electrons is the electron gun which is energized as previously described. The electrons emitted from the gun are controlled by the grid 51 and focused by the electrodes 47, 45 and impinged at high velocities on the emissive electrode 41 which is formed as described above. The secondary electrons pass through the insulated film and positively polarized surface region of the emissive electrode to the output electrode 43. A suitable load circuit is connected between the output electrode 43 and emissive electrode 41.

In certain instances it has been found that the photo-emissive property of the cathode 3 (see Fig. 1) is greatly reduced or may be almost entirely destroyed by the admission of oxygen preceding the final evacuation of the envelope. In some instances the photo-emissive properties may be restored but we have devised an arrangement which permits separate treatment of the photo-sensitive cathode and secondary emissive or multiplying electrode which will be described in connection with Fig. 4.

Referring to Fig. 4, an evacuated envelope 71 is divided into two portions 73, 75 by a thin glass diaphragm 77. Within one portion 73 are located an emissive electrode 79 and an output electrode 81. Within the other portion 75 are arranged a photo-sensitive cathode 83, and a pair of focusing anodes 85, 87. The focusing electrodes 85, 87 are biased positively with respect to the cathode 83 by batteries 89, or the like. The cathode is connected to the negative terminal of a battery 91. The emissive electrode 79 is connected to the positive terminal of battery 91. The output electrode 81 is connected to the positive terminal of a collector battery 93. The negative terminal of this battery 93 is connected to a load or work circuit represented as a resistor 95 which is connected to the emissive electrode as shown. A mobile degassed metal ball 97 is included within the envelope.

In preparing this tube the oxidized aluminum electrode and the other electrodes are mounted within their respective portions of the envelope. Both portions are highly exhausted, baked at 500° C. for one hour, and cooled to room temperature. If the photo-sensitive electrode is made of silver or the like, the procedure for treating this portion of the envelope is as follows: The silver is activated with oxygen and caesium until a highly photo-sensitive surface is obtained in the conventional manner. This portion is then sealed off at the seal 2.

The portion containing the secondary emissive electrode is then treated by distilling therein an alkali metal, caesium, for example. The tube is baked at approximately 200° C. for approximately ten minutes, and then cooled to room temperature. Pure oxygen is then admitted into this section for a short time. This portion is then re-evacuated to a degree which prevents ionization in normal operation, and sealed off at the seal 80. The thin glass diaphragm is finally broken by the metal ball 97.

In the operation of this device, Fig. 4, a beam of light from source 99 is focused through a suit-

able window 101 on to the photo-sensitive cathode 83. The beam of light striking the cathode causes primary electrons to be emitted. These electrons are focused and accelerated by the electrodes 85, 87. The primary electrons, travelling at high velocity, impinge on the secondary emissive electrode 79 which emits large numbers of secondary electrons which are attracted to the positively biased output electrode 81.

In view of the foregoing it will be apparent that our improved electrode is not limited in its application to a device or system of the type shown and described. For example, it is also capable of use in rectifiers, such as that disclosed by Slepian, wherein a copious substantially non-varying source of electrons is desirable.

Another application of our invention may possibly be found in the television field and particularly in connection with the composite mosaic targets that are utilized in cathode ray tubes of the transmitting type for the conversion of an optical image thereon into a train of impulses corresponding thereto. That is to say, it may be found feasible to substitute aluminum particles, treated according to our invention, for the silver particles now used on such targets and to scan the aluminum particles by a fine point of light in lieu of the cathode ray customarily utilized.

Although we have stated that electrolytically oxidized aluminum is our preferred electrode material, it is not to be understood that we are limited thereto. In fact, the aluminum may be oxidized by other than electrolytic methods. We have also found that beryllium, magnesium and silicon if provided with a sensitized insulating layer of the respective oxide also copiously emit electrons under electron impact, though not as yet as satisfactory as the treated aluminum surface. In addition, a layer of willemite upon a conducting surface, when sensitized, exhibits the same effect. In general it appears that any sufficiently resistive film upon a conductive surface, properly sensitized to yield a true high secondary emission, will act in a similar manner.

It is obvious from the foregoing that, by our invention, we have provided a source of electrons which is vastly more efficient in certain respects than sources heretofore known and that our improved electron source may be utilized in many ways too numerous to mention.

In the claims it is to be understood that the terms "secondary electrons" and "secondary emission" are to be construed as including both true secondary electron emission and electron emission by reason of electrostatic forces.

We are aware of other modifications of our invention that will be apparent to those skilled in the art. Our invention, therefore, is not to be restricted except by the spirit of the following claims.

We claim as our invention:

1. The method of preparing an aluminum electrode which comprises oxidizing the surface thereof, subsequently depositing a very thin layer of alkali metal upon the oxidized surface and thereafter oxidizing the said alkali metal layer to render it capable of high true secondary emission.

2. The method of preparing electrodes in a tube containing an aluminum electrode having an oxidized surface and a photo emissive electrode for electronic multiplication which comprises separating said tube in portions; one portion con-

taining said aluminum electrode, the other portion containing said photo emissive electrode; evacuating said portions; baking said tube; re-evacuating the portion containing the photo emissive electrode; oxidizing the surface of said electrode; treating said oxidized surface with an alkali metal; re-evacuating said portion; re-evacuating the other portion; depositing a very thin layer of alkali metal upon the oxidized surface of said aluminum electrode, baking both of said portions and thereafter oxidizing said alkali metal layer to render it capable of high secondary emission; re-evacuating said portion, and thereafter making said separate portions into connected portions.

3. An electrode comprising a conductive base, a surface layer of an oxide of an alkali metal and an interposed layer of an insulating material which remains highly resistive in the presence of the alkali metal of which said oxide is formed.

4. The invention as set forth in claim 3 wherein said alkali-metal-oxide layer is sub-microscopic in thickness.

5. The invention as set forth in claim 3 wherein said layer of insulating material is sub-microscopic in thickness.

6. The invention as set forth in claim 3 wherein said insulating layer is constituted essentially of willemite.

7. The invention as set forth in claim 3 wherein said insulating layer is constituted essentially of silicon oxide.

8. An electrode comprising a base formed of a metal whose oxide remains highly resistive in the presence of an alkali metal, a layer of oxide of the metal of which said base is formed on said base, and a surface coating of an oxide of an alkali metal on said oxide layer.

9. The invention as set forth in claim 8 wherein said base is constituted essentially of aluminum.

10. The invention as set forth in claim 8 wherein said base is constituted essentially of beryllium.

11. The invention as set forth in claim 8 wherein said base is constituted essentially of magnesium.

12. The invention as set forth in claim 8 wherein said surface coating is constituted essentially of caesium oxide.

13. Method of achieving copious electron-emission from an electrode comprising a conductive vase, a surface layer of an oxide of an alkali metal and an interposed layer of an insulating substance which remains highly resistive in the presence of the alkali metal of which said oxide is formed, said method comprising bombarding said alkali-metal-oxide layer with electrons to release a stream of secondary electrons therefrom and to thereby create an electrical charge adjacent thereto which is positive with respect to said conductive base, and then utilizing said positive charge to draw electrons from said conductive base through said insulating layer.

14. Method of achieving copious electron-emission from an electrode constituted of an insulating layer and a conductive layer, said method comprising polarizing said insulating layer electrically positive with respect to said conductive layer and utilizing the positive charge on said insulating layer for extracting electrons from said conductive layer.

VLADIMIR K. ZWORYKIN.
LOUIS MALTER.