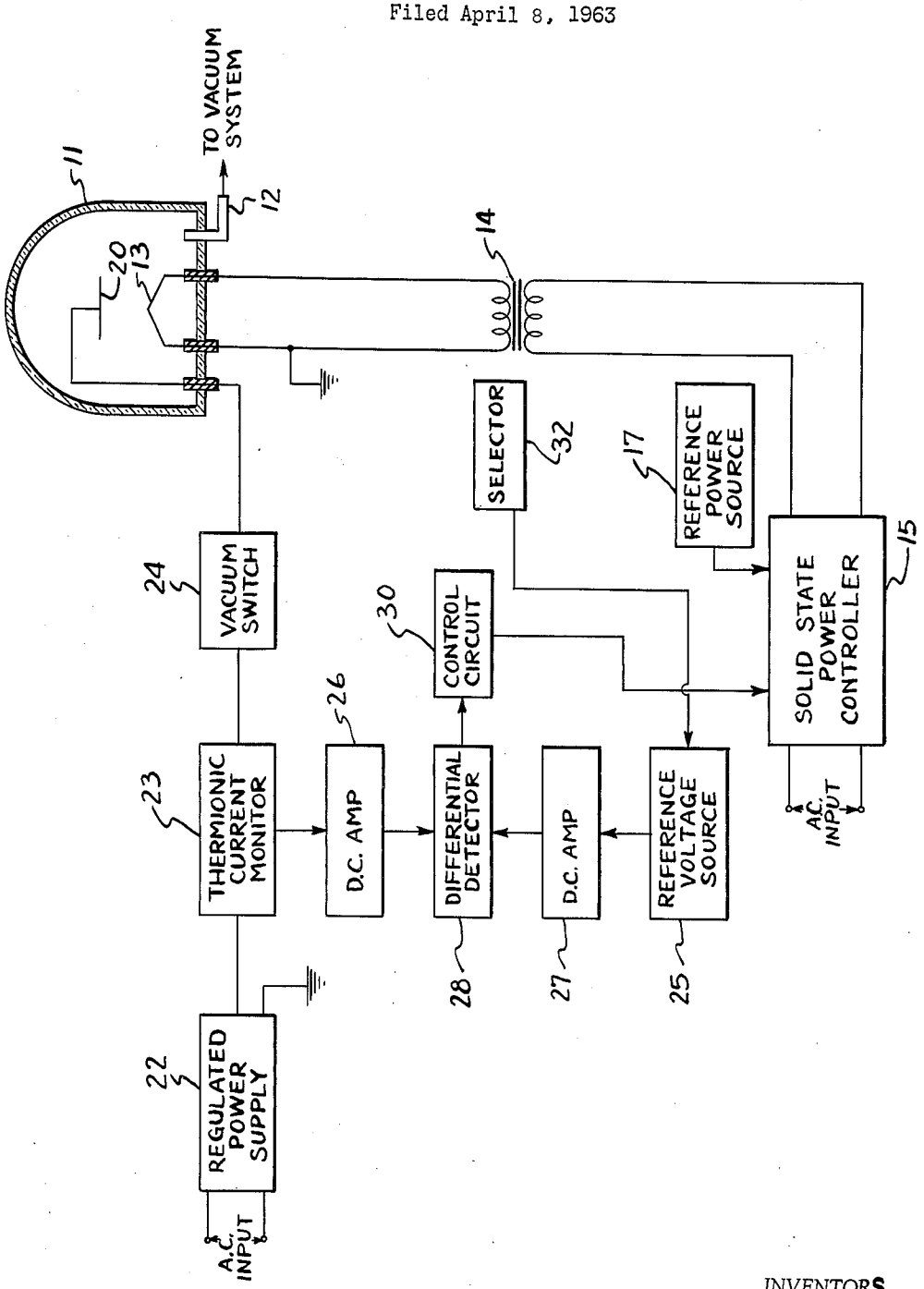
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THERMIONIC EVAPORATION RATE CONTROLLER

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THERMIONIC EVAPORATION RATE CONTROLLER

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The present invention relates to a thermionic evaporation rate controller and, more specifically, to a system for improving the repeatability of metal film evaporation processes for forming film-type resistors or the like.

In evaporation processes such as those for evaporating metal to form film-type resistors or the like wherein it is desirable for the processes to be consistent and repeatable, it is necessary to maintain a constant filament temperature in the evaporation chamber throughout an evaporation cycle and to repeat this temperature during successive evaporation cycles. The conventional wattmeter method of temperature control is based upon maintaining a constant power input to the filament. However, it has been observed that the filament temperature gradually increases throughout the evaporation cycle with a constant input to the filament, this being attributed to the fact that as the filament supports increase in temperature, less and less heat is conducted away from the filament so that the temperature thereof rises. Additionally, small variations in line voltage are not detected by the wattmeter due to the inherent sensitivity of the meter. Accordingly, it has been desirable to provide a system having improved control over filament temperature which may be utilized in place of the conventional wattmeter system.

An object of this invention is to provide a system for improving the repeatability of metal film evaporation processes by an improved control over filament temperature. In this connection, an object of this invention is to provide a thermionic evaporation rate controller utilizing a thermionic emission principle for maintaining a substantially constant filament temperature. Further in this connection, an object of this invention is to provide a thermionic evaporation rate controller for maintaining a substantially constant filament temperature and a substantially constant rate of evaporation during many successive cycles of operation. Accordingly, an object of this invention is to provide a thermionic evaporation rate controller of this type which allows for increased batch-to-batch repeatability.

Another object of this invention is to provide a completely automatic thermionic evaporation rate controller. Additionally, an object of this invention is to provide a thermionic evaporation rate controller for maintaining a constant filament temperature even in the face of small variations in the line voltage.

A more specific object of this invention is to provide a thermionic evaporation rate controller which accomplishes automatic control by comparing the filament emission current to a reference current and controlling the power input to the filament in response to the differential current.

A general object of this invention is to provide an improved thermionic evaporation rate controller which is characterized in its uniformity, repeatability, efficiency, reliability and economy of operation.

Other objects and advantages of this invention will become apparent upon reading the attached detailed description and upon reference to the drawing.

While the invention has been described in connection with a certain preferred embodiment, it is to be understood that the invention is not intended to be limited to

the disclosed embodiment, but, on the contrary, the invention is intended to cover the various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

Referring to the drawing, a standard evaporation chamber **11** is illustrated wherein metal may be evaporated to form film-type resistors or the like, the evaporation chamber preferably being an evacuation chamber of the bell jar type which is connected to a vacuum system through an outlet connection **12**, though any suitable evacuation chamber may be utilized. A filament **13** is provided in the evaporation chamber for controlling the rate of evaporation therein, and current is supplied to the filament through a filament transformer **14** by a solid state power controller **15**.

The solid state power controller is a commercially available unit which is utilized as a power regulating device, such controllers being manufactured by Labline Inc. under the trade name "Dynastat." The solid state power controller is so designed that current flows in the output thereof during a portion of the power cycle as determined by the amplitude of a control signal applied to a control input thereof. Thus, the power or current applied to the filament is a function of the control signal applied to the solid state power controller. In the instant case, a reference or bias input signal is applied to the solid state power controller **15** by a reference power source **17** and the amplitude of the reference signal is such that a desired output current is normally provided by the solid state controller, the output current being varied from the reference level in accordance with the control signal.

In accordance with the present invention, control circuitry is provided for regulating the output of the solid state controller in accordance with the thermionic emission of the filament so that the power applied to the filament in the evaporation chamber is controlled and a constant filament temperature is maintained through an evaporation cycle as well as during subsequent evaporation cycles. In this connection, circuitry is provided for maintaining a substantially constant flow of filament emission current (i.e., thermionic current) since, in vacuum processes, the filament temperature is proportional thereto. The thermionic evaporation rate controller includes an anode or plate circuit associated with the filament, and means responsive to the thermionic current flow in the plate circuit for controlling the output of the solid state power controller associated with the filament input.

Referring to the drawing, a plate or anode **20**, which may take any desired form, is provided in the evaporation chamber **11** and is positioned parallel to the filament **13**. The anode **20** is preferably formed of nickel because of the high electron collection characteristics of nickel. Since the filament **13** heats up during each evaporation cycle, the filament may be used as a source of electrons, it being well known that metals emit electrons when heated, and the plate or anode **20** may be utilized as an electron collector. Thus, by applying a fixed, direct current potential between the filament and the anode, the current flowing therebetween may be measured during an evaporation cycle and the power applied to the filament may be controlled in accordance with the measured current, the number of electrons emitted and thus the current flowing at any instant during an evaporation cycle being proportional to the emitter temperature (i.e., the filament temperature). This relationship with a fixed anode-to-filament potential may be seen by reference to the following equation, which sets forth the flow of current in the plate circuit:

$$I = SAT^2\left(\frac{0.44\epsilon^{1/2} - b}{T}\right)$$

wherein, I=the total current flowing in the plate circuit (including the thermionic current and the current due to the Schottky effect); S=the area of the filament; A=a constant; T=the desired constant filament temperature; ϵ=the electric field intensity of the voltage applied to the filament; b=11,600EW, and EW=the work function of the filament metal.

As illustrated in the drawing, a regulated supply **22** is provided for maintaining a steady direct current potential between the anode **20** and the filament **13**, the regulated power supply **22** being connected to the anode through a thermionic current monitor **23** and through a vacuum switch **24**. The thermionic current monitor **23** is provided to monitor the thermionic current flowing in the plate circuit and to provide an output voltage which is proportional to the thermionic current flowing. Preferably, the thermionic current monitor is a conventional meter which provides a visual indication of the thermionic current flowing in the plate circuit and which includes a resistor across which an analog or D.-C. output voltage is provided that is proportional to the thermionic current. The vacuum switch **24** is included in the plate circuit as a safety device, the vacuum switch open circuiting the plate circuit during periods in which the evaporation chamber is being loaded, when physical contact between the anode or plate **20** and ground by an operator is possible, so that the operator is protected.

The output voltage provided by the thermionic current monitor **23** is compared with a D.-C. or analog reference voltage provided by a reference voltage source **25**, the output of the reference voltage source being preset to correspond to a desired level of thermionic current which corresponds to a desired filament temperature and the difference between the voltages compared being utilized to control the solid state power controller **15**. In the instant case, the output of the thermionic current monitor **23** and the output of the reference voltage source **25** are respectively transmitted through D.-C. amplifiers **26** and **27** to inputs of a difference detector **28** which provides an output proportional to the difference between the input voltages applied thereto. Any commercially available difference detector may be utilized in the thermionic evaporation rate controller, and a typical difference detector is illustrated on page 504 of the text "Applied Electronics" by Truman S. Gray, wherein a "dual cathode-following triode" is illustrated. Briefly stated, the "dual cathode-following triode" is constructed so that the cathodes of two triodes are connected together and the plates of the triodes are connected to a common voltage source through identical loading resistors. The two voltages to be compared are applied to the grids of the triodes and an output is provided between the plates.

Referring again to the drawing, the output of the difference detector is applied to a control circuit **30** which controls operation of the solid state power controller. The control circuit **30** is a standard circuit designed to provide an output only when the output provided by the difference detector **28** indicates that the current monitor output voltage exceeds the reference voltage, the output thereof having sufficient amplitude to take over complete control of the solid state controller. In essence, the control circuit **30** operates as a switch responsive to an output having a prescribed polarity for applying a control signal to the solid state power controller which is substantially greater than the reference or bias input signal so that the control signal "swamps out" the effect of the reference or bias input signal.

When no output is provided by the difference detector **28** or the output thereof indicates that the reference voltage exceeds the current monitor output voltage, no output is provided by the control circuit so that the solid state power controller continues to provide an output as determined by the bias control signal. In the instant case, the bias control signal is so chosen that an output is provided by the solid state power controller which causes current to be applied to the filament **13** which is somewhat above the required power level for an evaporating operation. In turn, when an output is provided by the difference detector indicating that the current monitor output voltage exceeds the reference voltage, the control circuit **30** provides an output which takes over complete control of the solid state power controller **15** and renders the solid state power controller inoperative so that zero power is provided at the output thereof and thus zero current is applied to the filament **13**. Therefore, it may be seen that the output of the solid state power controller is varied between the zero power and a reference power level to maintain a substantially constant thermionic current flow from the plate **20** to the filament **13** and thus to maintain a substantially constant filament temperature, the control circuit **30** operating as a control switch for switching the solid state power controller "on" and "off." The filament temperature will actually fluctuate slightly about the desired temperature since the power provided by the solid state power controller is varied between a value less than that required and a value greater than that required for the desired evaporating operation.

For a typical operation of the thermionic evaporation rate controller, let it be assumed that initially the filament temperature is below the desired level so that initially zero output is provided by the difference detector **28** which allows the reference level output voltage to be provided by the solid state power controller and reference current to be applied to the filament **13**. As long as the filament temperature remains at or below the desired temperature level for the desired evaporation rate as determined by the presetting of the output of the reference voltage source **25**, the thermionic current flowing will be such that the output of the thermionic current monitor **23** will be less than the output of the reference voltage source. Under this condition, the output of the difference detector **28** is such that the output of the control circuit **30** is zero and, therefore, the solid state power controller **15** remains completely under control of the reference voltage provided by the reference power source **17**. Since the reference or bias voltage level was chosen such that the current applied to the filament **13** by the solid state power controller **15** is greater than that required to raise the temperature of the filament **13** to the desired temperature level, the temperature of the filament **13** will eventually begin to exceed the desired temperature level, causing an increase in the thermionic current flow in the plate or anode circuit. Under such conditions, the output of the thermionic current monitor **23** will be greater than the output of the reference voltage source **25** so that an output is provided by the difference detector **28** which renders the control circuit **30** operative. When the control circuit **30** is rendered operative, an output is provided thereby which takes over complete control of the solid state power controller, i.e., "swamps out" the effect of the reference power source output so that the solid state power controller output is completely cut off. Since the solid state power controller output is cut off, no current is applied to the input of the filament **13** so that the filament temperature will begin to drop.

When the temperature of the filament drops below the desired temperature level, the thermionic current flow will have been reduced such that the output of the thermionic current monitor **23** is less than the output of the reference voltage source **25**. Under these conditions, the output of the difference detector **28** will again be such that the control circuit **30** is rendered inoperative. Accordingly, the reference voltage signal of the reference power source **17** again will take over control of the solid state power controller **15** so that the reference current is again applied to the input of the filament **13**. Thus, throughout the evaporation cycle, the output of the solid state power

controller will be cyclically switched between zero value and a reference value, and the filament temperature will be maintained at substantially the desired temperature level throughout the evaporation cycle. As long as the output of the reference power source **17** and the output of the reference voltage source **25** are not varied, the temperature of the filament **13** will also be maintained at the same desired temperature level during subsequent evaporation cycles. If, during subsequent cycles, it is desirable to vary the rate of evaporation, this may readily be accomplished by changing the output level of the reference voltage source **25**, only the maximum filament current being varied by changing the output level of the reference power source **17**. For the purpose of presetting the output level of the source **25**, a selector **32** is provided.

Thus, it may be seen that a thermionic evaporation rate controller has been provided for maintaining a substantially constant filament temperature so that a constant rate of evaporation is provided, the thermionic evaporation rate controller allowing for increased batch-to-batch repeatability. Further, it may be seen that the thermionic evaporation rate controller will remain a constant filament temperature even in the face of small variations in the line voltage since operation is not dependent upon the line voltage, but rather is dependent upon thermionic current flow induced by the filament temperature. Additionally, it should be noted that the control circuit could be designed to operate as a proportional controller rather than as an "on-off" controller so that closer temperature control may be provided.

Though the invention has been described with both the anode and the filament enclosed in the evacuated chamber, the invention as claimed is intended to cover those embodiments wherein the anode is positioned outside the evacuated chamber or is a part of the evacuated chamber housing itself. Additionally, the invention as claimed is intended to include any means for varying the rate of evaporation in response to thermionic current flow, for example, a shutter for varying the filament effectiveness in lieu of means for varying current supplied to the filament. Further, while the invention has been described for controlling the rate of evaporating metal to form film-type resistors or the like, it will be obvious to one with ordinary skill in the art that any desired evaporation process may be controlled thereby. Accordingly, the claims in setting forth the term "film-type resistors or the like" are intended to cover a thermionic evaporation rate controller for controlling any desired evaporation process.

We claim as our invention:

1. In a thermionic evaporation rate controller for evaporating metal to form film type resistors or the like, the combination which comprises, an evaporation chamber and means for evacuating said chamber, a filament within said evaporation chamber for controlling the rate of evaporation, a variable power supply associated with the filament for supplying current thereto, an anode associated with the filament, a direct voltage source connected between the anode and the filament so that thermionic current flows from the filament to the anode, and means responsive to the magnitude of thermionic current flow for controlling the variable power supply to vary the current supplied to the filament so that the filament temperature is maintained at substantially a constant desired level.

2. In a thermionic evaporation rate controller for evaporating metal to form film type resistors or the like, the combination which comprises, an evaporation chamber and means for evacuating said chamber, a filament within said evaporation chamber for causing the metal to be evaporated, a power supply associated with the filament for supplying current thereto, an anode associated with the filament, a direct voltage source connected between the anode and the filament so that thermionic current flows from the filament to the anode, and means responsive to the magnitude of the thermionic current flow for controlling the effectiveness of the filament so that the rate of evaporation is controlled.

3. In a thermionic evaporation rate controller for evaporating metal to form film type resistors or the like, the combination which comprises, an evaporation chamber and means for evacuating said chamber, a filament within said evaporation chamber for controlling the rate of evaporation, a variable power supply associated with the filament for supplying current thereto, an anode associated with the filament, a direct voltage source connected between the anode and the filament so that thermionic current flows from the filament to the anode, means defining an evacuated chamber enclosing the filament and the anode, and means responsive to the magnitude of thermionic current flow for controlling the variable power supply to vary the current supplied to the filament so that the filament temperature is maintained at substantially a desired level.

4. In a thermionic evaporation rate controller for evaporating metal to form film type resistors or the like, the combination which comprises, an evaporation chamber and means for evacuating said chamber, a filament within said evaporation chamber for controlling the rate of evaporation, a variable power supply associated with the filament for supplying current thereto, means including an anode associated with the filament and an evacuated chamber for enclosing the filament, a direct voltage source connected between the anode and the filament so that thermionic current flows from the filament to the anode, and means responsive to the magnitude of thermionic current flow for controlling the variable power supply to vary the current supplied to the filament so that the filament temperature is maintained at substantially a desired level.

5. In a thermionic evaporation rate controller for evaporating metal to form film type resistors or the like, the combination which comprises, an evaporation chamber and means for evacuating said chamber, a filament within said evaporation chamber for controlling the rate of evaporation, a variable power supply associated with the filament for supplying current thereto, an anode associated with the filament, a direct voltage source connected between the anode and the filament so that thermionic current flows from the filament to the anode, means for monitoring the thermionic current flow, means for providing a reference current, and means for comparing the thermionic current amplitude with the reference current amplitude and for controlling the variable power supply in accordance with the differential current to vary the current supplied to the filament so that the filament temperature is maintained at substantially a desired level.

6. In a thermionic evaporation rate controller for evaporating metal to form film type resistors or the like, the combination which comprises, an evaporation chamber and means for evacuating said chamber, a filament within said evaporation chamber for controlling the rate of evaporation, a variable power supply associated with the filament for supplying current thereto, an anode associated with the filament, a direct voltage source connected between the anode and the filament so that thermionic current flows from the filament to the anode, means for monitoring the thermionic current flow and for providing an analog output representative thereof, variable means for providing an analog output representative of a current having a desired reference value, and means for comparing the analog outputs and for controlling the variable power supply in accordance with the difference therebetween to vary the current supplied to the filament so that the filament temperature is maintained at substantially a desired level.

7. In a thermionic evaporation rate controller for evaporating metal to form film type resistors or the like, the combination which comprises, an evaporation chamber and means for evacuating said chamber, a filament within said evaporation chamber for controlling the rate

of evaporation, a variable power supply associated with the filament for supplying current thereto, an anode associated with the filament, a direct voltage source connected between the anode and the filament so that thermionic current flows from the filament to the anode, means for monitoring the thermionic current flow and for providing a D.-C. output representative thereof, variable means for providing a D.-C. output representative of a current having a desired reference value, a differential detector for comparing the D.-C. outputs and for providing an output representative of the difference therebetween, and means responsive to the differential detector output for controlling the variable power supply to vary the current supplied to the filament so that the filament temperature is maintained at substantially a desired level.

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RICHARD M. WOOD, *Primary Examiner.*