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Anderson et al.

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[54] **COATING CONTROL SYSTEM**

[75] Inventors: **Quinn S. Anderson,** Chatsworth; **Berton P. Levin,** Santa Monica; **Jackie D. Thomson,** Los Angeles, all of Calif.

[73] Assignee: **The Sierracin Corporation,** Sylmar, Calif.

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[52] **U.S. Cl.**....................**118/8,** 118/49.5, 219/69 G, 324/65

[51] **Int. Cl.**..........................**B05b 15/00,** C23c 13/08

[58] **Field of Search**..................118/7, 8, 6, 48–49.5; 250/83.3 D, 218 TH; 324/65 G; 219/272

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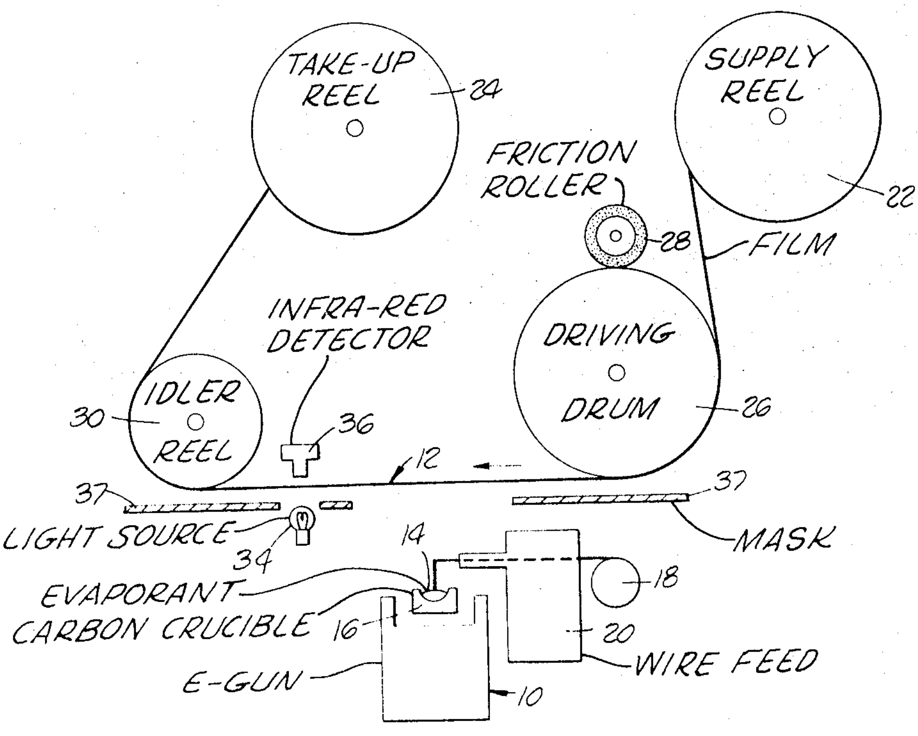
Primary Examiner—Morris Kaplan
Attorney—Lyon and Lyon

[57] **ABSTRACT**

There is disclosed herein a system for controlling the resistivity of a metal which is deposited on a moving film substrate. An electron beam gun is positioned adjacent the moving film substrate for providing the metal coating on the substrate. The resistivity of the coating is continuously monitored by detecting electromagnetic radiation, such as infrared, emanant from the coating for providing an output signal which is a function of the resistivity. This signal is applied to a comparator network and compared to predetermined reference levels for correcting long term resistivity drifts as well as short term, or transient, changes in resistivity. The output of the comparator network is connected to the electron beam gun to control the evaporation rate thereof and to thus control resistivity of the coating.

11 Claims, 3 Drawing Figures



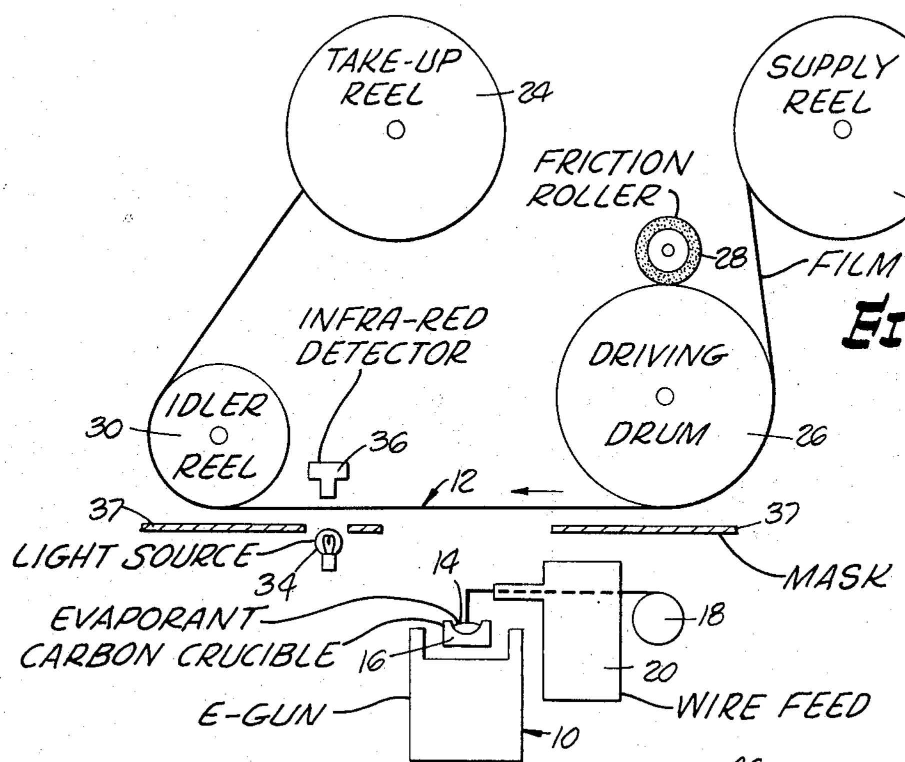


FIG. 1.

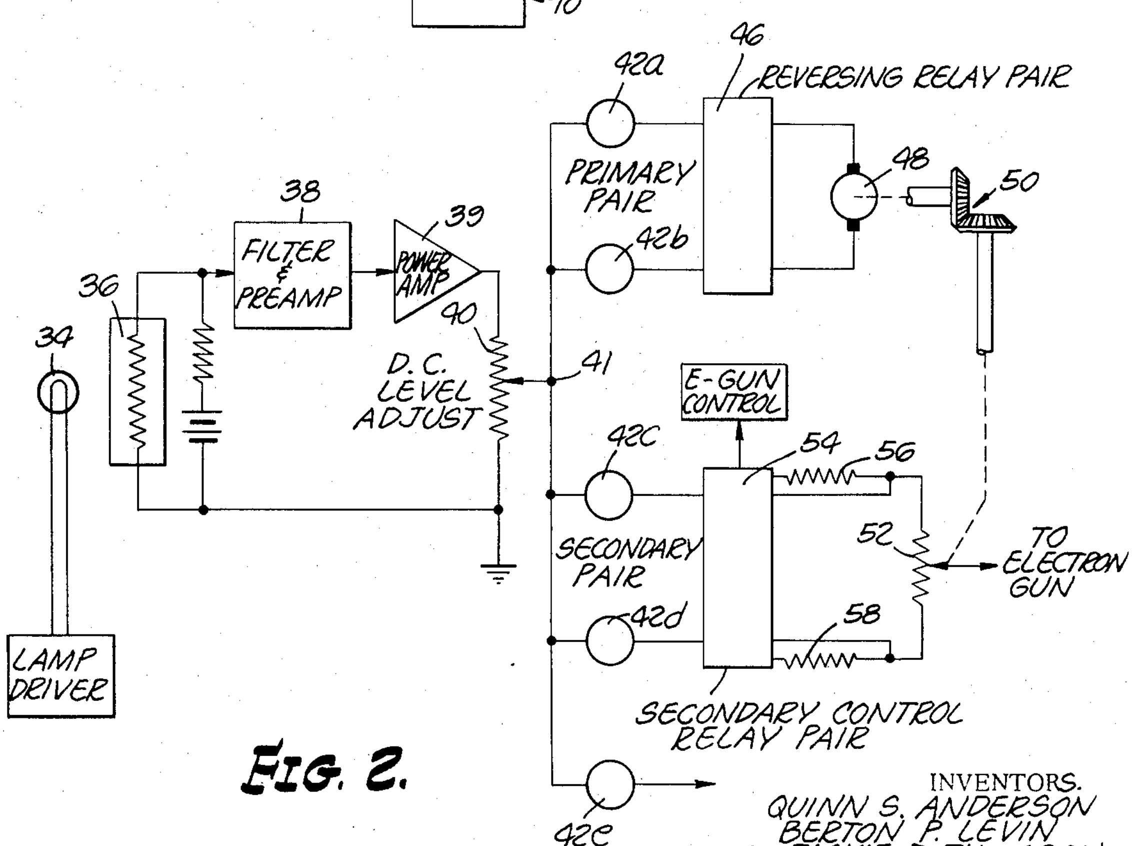


FIG. 2.

INVENTORS.
QUINN S. ANDERSON
BERTON P. LEVIN
BY JACKIE D. THOMSON

Lyon & Lyon
ATTORNEYS

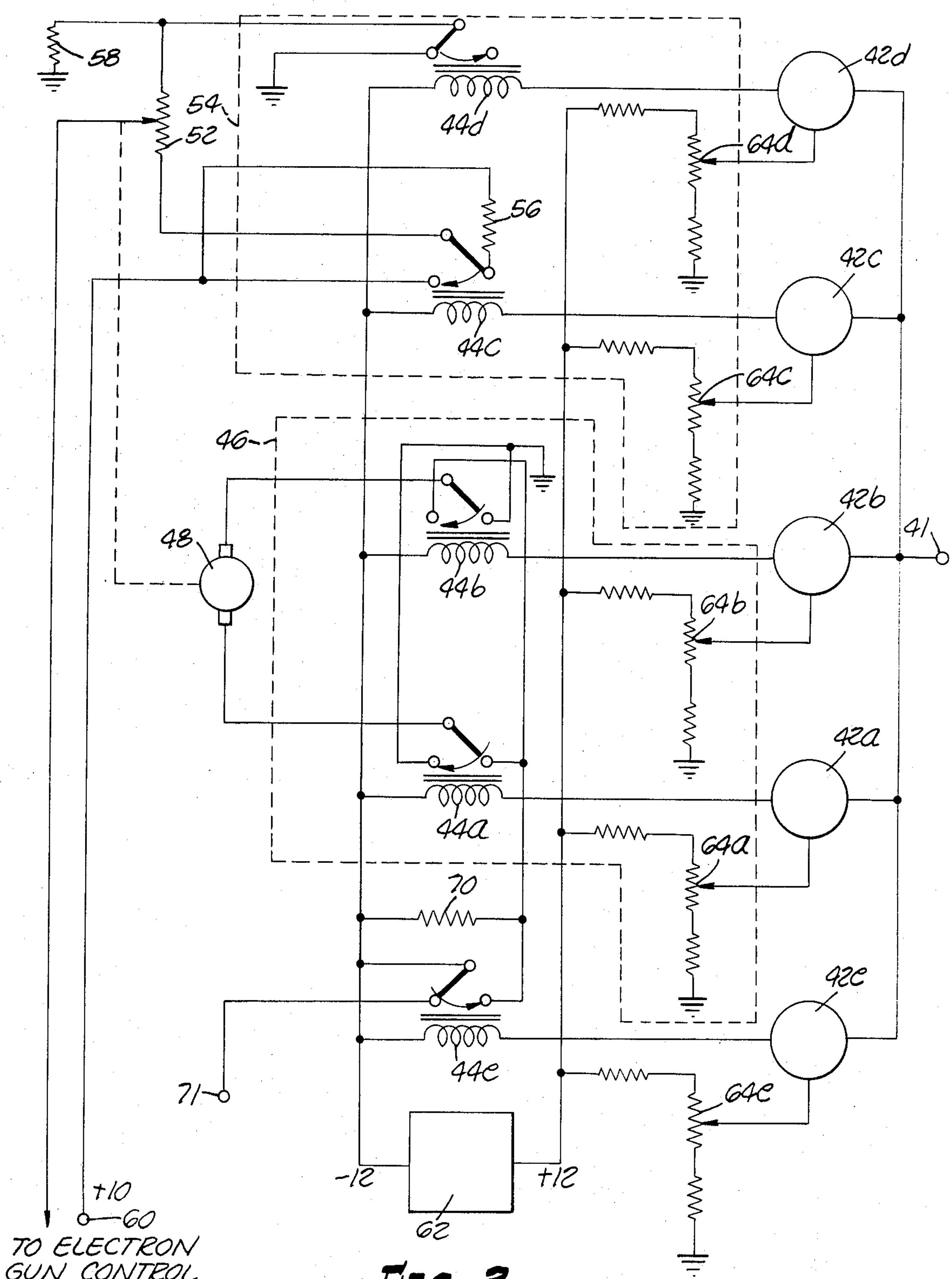


FIG. 3.

INVENTORS.
QUINN S. ANDERSON
BERTON P. LEVIN
JACKIE D. THOMSON
BY Lyon & Lyon
ATTORNEYS

COATING CONTROL SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to vacuum deposition of metal to form a transparent metalized film, and more particularly to a control system for maintaining the resistivity of such coating within desired limits.

It has been proposed to provide electrically heated closures such as for automobiles by the incorporation of a hard plastic film bearing an electrically conductive metal coating, along with interlayer material, between sheets of rigid transparent glass or plastic. This type of construction is described in greater detail in assignee's copending U.S. Pat. application Ser. No. 22,878, filed Mar. 26, 1970, the disclosure of which is expressly incorporated herein by reference. In this type of construction it is necessary that the conductive metal coating on the hard plastic film have a prescribed surface resistivity distribution which when electrically energized, dissipates power in a manner optimum for the particular deicing function of the final article. The deposition of the coating on the film involves the utilization of metal deposition techniques.

It has been found that the deposition techniques previously developed do not always provide the required surface resistivity distribution concomitant with the necessary visible light transmission needed for commercially acceptable electrically heated closures. The present invention is directed to a novel system which is effective in controlling the surface resistivity distribution of the deposit of metal film and permits the production of metal coated transparent hard plastic film on a continuous and large-scale basis.

Examination of vapor deposition techniques from other arts discloses that the control of the metal deposit formed by the vapor on a substrate is inadequate for maintaining the surface resistivity distribution required for electrically heated closures. Typical of such other techniques is that disclosed in U.S. Pat. No. 3,397,672. According to this patent, the power supplied to the electron guns used to vaporize the coating metal is compared to a preset standard of power in an attempt to obtain a uniform metal deposit on the substrate. The present standard is determined empirically and coincides with a level of electron gun power which at one set of operating parameters of the system gives the desired deposit. Under operating conditions, the operating parameters may change or drift, and such condition is not compensated for by comparison of the electron gun power with the fixed preset standard of power. The present invention, by way of contrast, does not control the electron gun power by reference to a fixed standard of power. Instead, the ultimate property, viz, the surface resistivity is monitored and compared with predetermined levels to control the electron gun power from the standpoint of both long term resistivity drift and short term, or transient, resistivity change. This results in adjustment for changes in the operating parameters as is more fully hereinafter explained.

Furthermore, it is necessary to provide an overall control system which does not possess electrical continuity. The crucible-electron gun combination constitutes a diode which is occasionally subject to arc discharge by reason of the presence of vaporized material in the vacuum in the vicinity of the diode. When arc discharge occurs, a signal of substantial magnitude is propagated backwards through the control system to the error signal generation point effectively "swamping" the system. In order to avoid this feedback signal from progressing to the signal generation point, it is desirable to provide means which at one and the same time interrupt the electrical continuity without interrupting continuity of control. The present invention accomplishes this objective.

SUMMARY OF THE INVENTION

Briefly, the present invention comprises a novel servo control system for continuously monitoring and controlling the resistivity of a metal film deposited on a moving film substrate. The metal is applied by vacuum deposition of a metal, such as silver, gold, copper or the like, on a transparent plastic carrier film by means of an electron beam gun. The resistivity of the deposited metal is monitored by detecting electromagnetic radiation, such as infrared, emanant from the coating to derive a control signal. The control signal is used to control electron beam current of the electron beam gun. The control signal is applied to a comparator circuit employing a plurality of comparators. A first pair of comparators is used for control of long term drifts, while a second pair of comparators is used for control of short term, or transient, changes in resistivity.

It is accordingly an object of the present invention to provide a novel system for control of the continuous vacuum deposition of a conductive transparent metal film on a substrate.

More particularly, it is an object of the present invention to provide a novel means for the continuous deposition of metal film on a hard plastic substrate which metal film has the required surface resistivity distribution for electrically heatable closures.

Still another object of the present invention is a novel control system for controlling the surface resistivity distribution of continuously deposited transparent metal on a hard plastic substrate.

A further object of this invention is to provide a novel control system for controlling a characteristic of a deposited coating.

These and other objects and advantages of this invention will be apparent from the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a transport mechanism for the substrate which is metal coated in accordance with this invention;

FIG. 2 is a block diagram of the monitor and control system of this invention; and

FIG. 3 is a schematic diagram of a control portion of the system shown in FIG. 2.

DESCRIPTION OF PREFERRED EMBODIMENTS

Turning now to the drawings, an electron beam gun **10** is shown positioned below a moving substrate **12**. The electron beam of the gun is focused onto an evaporant metal **14** which is located in a crucible **16** recessed into the electron gun **10**. The evaporant metal **14** is stored in the form of wire on a spool **18**. The wire is fed to the crucible **16** by a feed mechanism **20**.

The film substrate **12** is transported from a supply reel **22** over the electron gun **10** to a take-up reel **24** by means of a friction driving drum **26**. This drum is rotated by a friction roller **28** which is connected by chains and a gear set to a reversible universal motor (not shown). An idler reel **30** maintains suitable tension on the substrate **12**.

The local resistivity of the metal deposit applied to substrate **12** is monitored by measuring the infrared (IR) transmission emanant from the metallized film **12**. Either the radiation transmitted through the film or the radiation reflected by the metal coating may be measured. For purposes of illustration an AC energized light source **34** and infrared detector **36** are shown placed on either side of the substrate **12** at a point immediately following the deposition area for measuring infrared transmission. Masks **37** may be provided. The output from the infrared detector **36** is electrically filtered, amplified, rectified, and then the magnitude of the resultant signal is compared with preset voltages to produce a difference signal. As will be described more fully subsequently, two preset voltages are used in control of long term resistivity drifts, and two preset voltages are used in control of short term resistivity changes. When a difference signal exists, a suitable correction signal is produced in a control system which changes the electron gun beam current to correct the evaporation rate.

The detector **36** is a segmented, low resistance, infrared detector with an optical interference, band-pass filter. The signal from the detector **36** is applied through a filter and a two-pole, narrow-pass pre-amplifier **38** to a full wave rectifying power amplifier **39**.

The resulting DC analog signal is applied to a potentiometer **40**, and is digitized to perform several "on" - "off" functions during a film deposition cycle. An analog-to-digital conversion of the analog signal from the potentiometer is performed by voltage comparators **42*a*** through **42*e***. The output of each comparator is, in logic parlance, either zero or one. Switching occurs when the analog signal rises above or falls below a fixed reference voltage at each comparator. Two pairs of comparators control electron beam gun current, with a first pair controlling long term drifts and a second pair controlling short term changes. A fifth comparator **42*e*** controls beam current rate of change. A sixth comparator may be provided for controlling film transport rate, but is not shown. The latter two comparators are not essential to the process of this invention.

The first pair of comparators **42*a*** and **42*b*** may be termed primary comparators and are used to control resistivity from the standpoint of long-term drift. Referring to FIGS. **2** and **3** to better illustrate this operation, assume that a surface resistivity is desired which corresponds to an infrared transmission of 40 percent, i.e., the freshly deposited film transmits 40 percent of the incident radiation in the wavelength range passed by the detector-filter combination. The reference voltage for one comparator **42*a*** is then set at a value equal to the DC analog signal from the potentiometer **40** on a terminal **41** (FIG. **3**) when the infrared transmission is 39 percent. Thus, when the signal from the detector **36** falls below a value corresponding to 39 percent transmission, the comparator **42*a*** energizes a relay **44*a*** in a control unit **46** which provides power to a DC motor **48**. This motor is connected via gear train **50** to a potentiometer **52**, such as a ten-turn helical potentiometer. This potentiometer is connected to a electron gun to control electron gun current. When this relay **44*a*** is energized, the wiper of the control potentiometer **52** is turned in a direction which decreases the current to electron gun **10**, thus reducing evaporation rate and increasing resistivity. When the transmission increases to a value greater than 39 percent, the same relay **44*a*** in the unit **46** removes power from the motor **48** and the correction of the electron gun current stops. If the transmission increases above **41** percent, the second comparator **42*b*** energizes relay **44*b*** in the unit **46** which causes the motor **48** to turn in the opposite direction, thus increasing the electron gun current. When the transmission falls below 41 percent the motor **48** stops. This transmission span, 39–41 percent, is referred to as the "dead band". It is dead in the sense that so long as the transmission remains within these limits no corrective action ensues, although it is to be appreciated that other transmission percentages or spans may be used.

The second pair of comparators **42*c*** and **42*d***, termed secondary comparators, are used to control brief pulse changes in resistivity. Assuming a dead band of 39–41 percent, these secondary comparators may be set to 38–42 percent. This interval 38–42 percent is referred to as the pulse correction band since transmission values outside this range result in correction for pulse-like errors. The secondary comparators actuate either of relays **44*c*** or **44*d*** in a control unit **54** which switch resistors **56** and **58**, respectively, in and out of series circuit with the potentiometer **52**. In the quiescent state the resistors **56** and **58** are in series with the potentiometer **52**. The resistor **56** is connected between a plus ten volt electron gun control system supply terminal **60** and the potentiometer **52**, and the resistor **58** is connected between the other end of the potentiometer **52** and ground. The switching operation of the resistors **56** and **58** can be illustrated as follows. In the event transmission falls below 38 percent, indicating that the metal deposit is too heavy, the power to the electron gun **10** is reduced by leaving the resistor **56** in circuit and switching the resistor **58** out of the series circuit with the potentiometer **52** to provide a reduced control voltage from the wiper of the potentiometer **52** to ground. This switching of resistor **58** out of series is accomplished by energizing relay **44*d***, thus providing a shunt across the resistor **58** to ground thereby grounding the negative end of potentiometer **52**. Similarly, when the transmission rises above 42 percent, the resistor **56** is switched out of circuit by the relay **44*c*** and the resistor **58** is left in circuit thereby providing a larger control voltage from the wiper of the potentiometer **52** to ground. The reference voltage for the comparators is provided by a suitable power supply **62**, and the voltage levels may be independently adjusted for each comparator by potentiometers **64*a*–64*d*** shown in FIG. **3**. This power supply also provides the required operating voltage for the comparators, motor **48** and relays.

The comparator **42*e*** may be provided, as noted earlier, and is connected with a relay **44*e*** to perform two functions. First, it serves to initially allow the motor **48** to run at a high speed in rapidly adjusting the potentiometer 52 when the IR transmission is above a large predetermined value. For example, when the apparatus is initially turned on, IR transmission is, of course, relatively high because deposition has not commenced. The comparator 42e may be set for an infrared transmission of 50 percent. With this arrangement, the motor 48 initially runs at a high speed to rapidly adjust the potentiometer 52 so that the beam current is brought up to the value required for deposition fairly quickly. When transmission falls below 50 percent as determined by the setting of potentiometer 64e and comparator 42e, the relay 44e is energized to unshunt a resistance 70 and to connect the minus 12 volt terminal to a wire feed relay output terminal 71. When the resistance 70 is unshunted by the relay 44e, this resistance is then in series with the motor 48 thereby causing it to run at a slower speed and thus adjust the potentiometer 52 at a slower rate so that the system does not tend to over-compensate and cause oscillations in the deposition. The terminal 71 provides a voltage to turn on the wire feed motor.

Another major feature of the present invention is provided by the regulation of the mechanical drive to the potentiometer 52 by the comparators 42a and 42b. This system makes a cumulative residual correction in the electron gun current. This correction accommodates long term slow drifts in the operating parameters of the system. In effect, the resistance of the coated substrate being produced in continually compared to a predetermined substrate product, and the gun current is adjusted to make the two products substantially identical. The passage of emitted electrons to the crucible, and passage of evaporated metal from the crucible to the film are both very sensitive to residual pressure in the vacuum chamber within which the apparatus of FIG. 1 is located. The pressure in the chamber changes over a period of time because of several factors including vacuum pump efficiency changes, pockets of gas released from the unwinding roll of film, outgasing of the film, outgasing of the wire feed, and so forth. The control system must provide the interrupted electrical continuity noted earlier while still compensating for long term, slow small amplitude changes by accumulating compensatory changes. The drift can be unidirectional as occurs when residual pressure increases by progressive accumulation of gas in the vacuum chamber. One way in which the interrupted electrical continuity is provided is by means of the motor-potentiometer wiper combination and relays described; however, it will be apparent to those skilled in the art that another means for providing electrical isolation such as optical, acoustical or fluid control systems can be used. Arrangements of this nature may be described as means for transmitting information relating to changes in amplitude, state or condition of the components in a control system, which means do not possess electrical continuity. Yet another feature of the present invention is the secondary correction provided by the switching of resistors 56 and 58. These resistors are operated only when deviation from the reference level is substantial, indicating an abrupt change in the operating parameters. Abrupt changes in the operating parameters might be too great to be handled by the slow drift correction system.

The invention has been particularly described with reference to a single electron gun. However, the use of a plurality of electron guns disposed laterally across the path of the substrate is contemplated, and in fact, is normally preferred. When a plurality of electron guns is used, the electro-mechanical control system previously described is provided for each gun.

The present invention also may be practiced by the deposit of metal on discrete sections of a substrate carried on a continuous web support. When practiced in this manner, the electrical system is augmented by a blanking circuit of the type familiar to those skilled in the art which interrupts the electron gun and metal evaporation process to accommodate the gaps present between the sections of substrate.

It is to be understood that the apparatus shown in FIG. 1 is normally contained in a vacuum chamber. The construction of this chamber is conventional and does not form a part of the present invention. It is generally desirable that operating parameters, e.g., pressure in the chamber, remain fairly constant during deposition. If, for example, the pressure changes abruptly and grossly, the deposition rate varies too rapidly for the motor driven potentiometer system to correct; however, the secondary correction provided by the switching in of the fixed resistors will correct fairly large deviations from quiescent operating conditions.

The invention is applicable to deposition of metal on any type of flexible hard film possessing suitable electromagnetic wave transmission, and particularly to transparent films such as polyethylene terephthalate (Mylar) and cellulose triacetate. Likewise, many metals can be applied in the manner herein described, although the highly electrically conductive metals such as gold, silver and copper are the most important.

The preferred source of vaporizing energy is an electron gun. Although the electron gun current is described as being controlled, it will be apparent that other variables may be controlled, such as the rate of feed of evaporant wire, a clutch which controls rate of film travel, or interposition of a screen which controls the rate of deposition by and as a function of the screen mesh size. Furthermore, other devices will perform the same function as an electron gun and all of them are included within the scope of this invention. The preferred detector system utilizes infrared radiation. The electromagnetic radiation can also be X-rays or any type of electromagnetic radiation capable of penetrating to some extent the substrate and metal deposit. The substrate is normally cleaned and/or pretreated prior to metal deposition. These techniques are familiar to those skilled in the art and need not be detailed herein.

The predetermined reference level inserted in the comparison means is established empirically. For example, a substrate and metal coating composition are selected. By a series of resistivity measurements on different coatings of the metal, the nature of the metal deposit which will provide the surface resistivity distribution fulfilling the heating requirements of the closure is pinpointed. The coated substrate selected is subjected to the intended electromagnetic radiation source, and the transmission detected in the form of an electrical signal. This signal is the predetermined reference level for use in the comparison means. If the substrate composition, metal, surface resistivity distribution, and/or radiation source is changed, a new reference level must be obtained in the manner indicated above.

The present embodiments of this invention are to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims therefore are intended to be embraced therein.

What is claimed is:

1. A control system for controlling resistivity of a deposit formed by deposition of metal on a moving substrate comprising

transport means for continuously moving said substrate,

deposition means mounted adjacent said substrate for depositing metal thereon,

monitoring means mounted adjacent said substrate for monitoring a characteristic of the metal deposited thereon which is a function of resistivity thereof, said monitoring means providing a control signal,

comparator means coupled with said monitoring means for receiving said control signal, said comparator means including a plurality of comparators for providing discrete output signals as a function of variation of said control signal respectively above and below a preset value representing a desired value of said characteristic, and

coupling means coupling said comparator means to said deposition means and responsive to said output signals for controlling said deposition means upon the occurrence of predetermined changes of said characteristic for controlling said resistivity.

2. A control system as in claim 1 wherein

said plurality of comparators comprises first and second comparators for providing discrete output signals when said control signal is a first magnitude respectively above and below said preset value, and comprises third and fourth comparators for providing discrete output signals when said control signal is a second magnitude respectively above and below said preset value, said second magnitude being greater than said first magnitude, and

said coupling means couples the output signals of said first and second comparators to said deposition means to compensate for long term resistivity changes, and couples the output signals of said third and fourth comparators to said deposition means to compensate for short term resistivity changes.

3. A control system as in claim 1 wherein

said characteristic monitored by said monitoring means includes electromagnetic transmission of the metallized substrate, and said desired value thereof is a percentage transmission value.

4. A control system as in claim 2 wherein

said coupling means includes electromechanical means operating impedance means, said impedance means being coupled to control said deposition means, and

said first and second comparators are coupled to said electromechanical means to control the operation thereof, and means couple said third and fourth comparators to said impedance means for affecting the impedance thereof.

5. A control system as in claim 2 wherein

said coupling means includes a motor controlled impedance, the motor being controlled by said output signals of said first and second comparators and said impedance being coupled to control said deposition means, and

fifth comparator means responsive to said monitoring means for controlling the speed of operation of said motor as a function of said characteristic of said metal deposit.

6. A control system for maintaining a variable substantially constant comprising

means for monitoring said variable to detect a characteristic thereof and to provide a control signal which varies as a function of change of said characteristic

comparator means coupled with said monitoring means for receiving said control signal, said comparator means comprising a first pair of comparators responsive to the limits of a first range of said control signal and respectively providing discrete output signals when said control signal varies to said limits, and a second pair of comparators for receiving said control signal and responsive to deviation thereof over a second greater range for providing discrete output signals when said control signal respectively reaches the limits of said second range,

means for controlling said variable, and

coupling means coupled between said comparator means and said means for controlling said variable and responsive to said discrete output signals from said first pair of comparators for compensating for long term drifts in said variable and responsive to said discrete output signals of said second pair of comparators for compensating for short term changes in said variable while providing non-electrically conductive path between said comparator means and said means for controlling said variable.

7. A control system for monitoring resistivity of a deposit formed by deposition of metal on a moving film substrate comprising

means adapted to contain coating metal adjacent to the path of the moving film substrate,

means for delivering vaporizing energy to said metal,

means for supplying electric power to said means for delivering vaporizing energy, said means for supplying electric power being coupled with vaporizing energy control means,

detection means adjacent said film substrate for continuously monitoring electromagnetic radiation emanant from the coated film substrate after deposition for providing an electrical signal, the magnitude of said signal being empirically related to the resistivity of the coated film substrate,

comparison means coupled with said detection means for receiving said electrical signal, said comparison means including a comparator network for providing output signals as a function of variation of said electrical signal from first and second predetermined reference levels, and means operated by the control signal from said comparison means for operating said vaporizing energy control means whereby power to said means for delivering vaporizing energy is varied to control the resistivity of the deposit.

8. A control system for a vacuum deposition system for the maintenance of the required surface resistivity distribution of the deposit formed by vapor deposition of metal on a moving film substrate comprising

means adapted to contain coating metal adjacent to the path of the film substrate,

means for delivering vaporizing energy to said metal,

means for supplying electric power to said means for delivering vaporizing energy, said means for supplying electric power being coupled with vaporizing energy control means,

detection means adjacent said film substrate for continuously monitoring the electromagnetic radiation emanant from the coated film substrate after deposition for providing an electrical signal, the magnitude of said signal being functionally related to the resistivity of the coated film substrate,

first and second comparison means coupled with said detection means for comparing said electrical signal (1) with a first predetermined reference level, and (2) with a second predetermined reference level, said first predetermined reference level corresponding to a narrower range of electromagnetic radiation percentage emanant from the coated substrate than said second predetermined reference level, each said comparison means providing a control signal when the magnitude of the electrical signal from the detection means deviates from a specific value related to its respective predetermined reference level, and

means operated by the control signal from said first comparison means for varying an output signal applied to said vaporizing energy control means to compensate for long term drifts in said resistivity, and means operated by said second comparison means for affecting said output signal to compensate for short term changes in said resistivity whereby vaporizing energy is varied to achieve the required surface resistivity distribution of the deposit.

9. A control system as in claim 8 wherein

said means operated by the control signal from said first comparison means comprises motor means coupled with potentiometer means, said potentiometer means being coupled to said vaporizing energy control means for supplying said output signal to said vaporizing energy control means, and

said means operated by said second comparison means comprises controllable impedance means coupled with said potentiometer.

10. A control system as in claim 9 wherein

said means for delivering vaporizing energy to said metal comprises an electron beam gun, and said electromagnetic radiation is infrared radiation.

11. A control system as in claim 8 wherein

said first and second comparison means include electromechanical means providing conducting electrical isolation between said detection means and the means operated by the control signals from said first and second comparison means.

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