Aug. 25, 1970 N. CONSTANTINE ET AL 3,525,863
DIFFERENTIAL EMISSION X-RAY GAUGING APPARATUS AND METHOD USING TWO MONOCHROMATIC X-RAY BEAMS OF BALANCED INTENSITY
Filed Dec. 28, 1967 2 Sheets-Sheet 1

FIG. 1

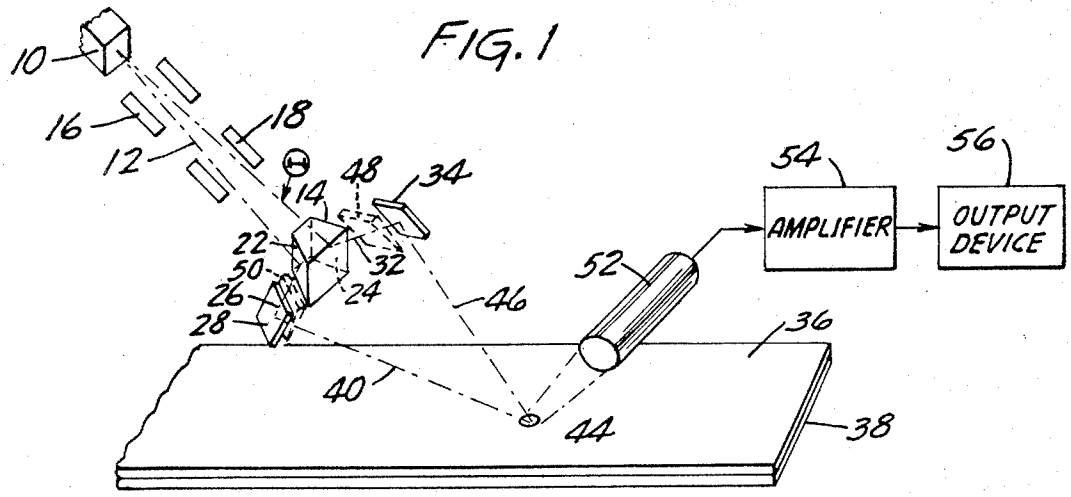



FIG. 2

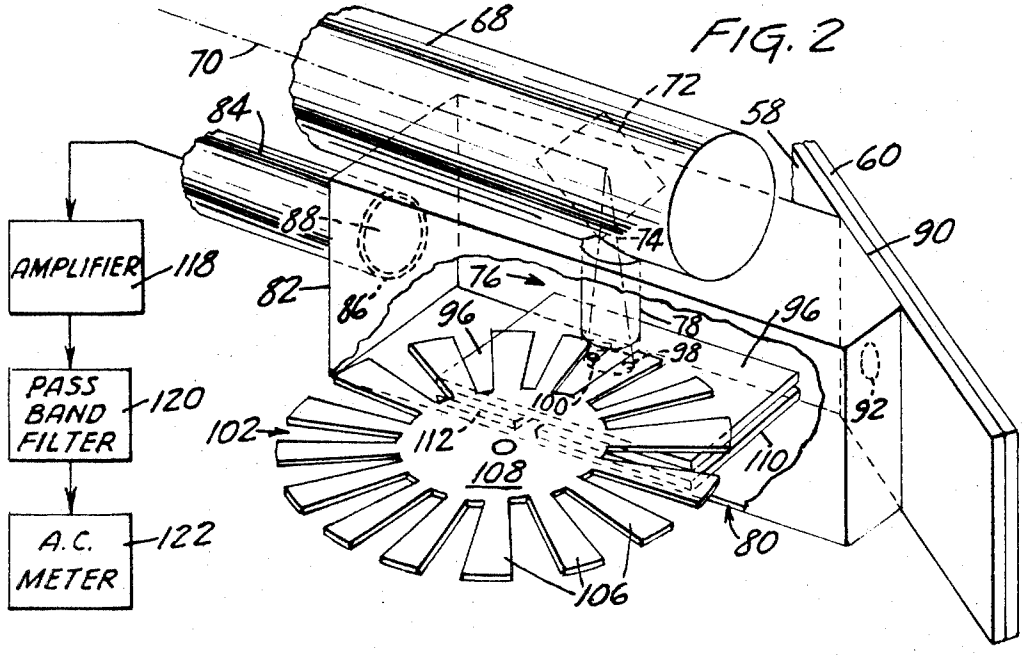
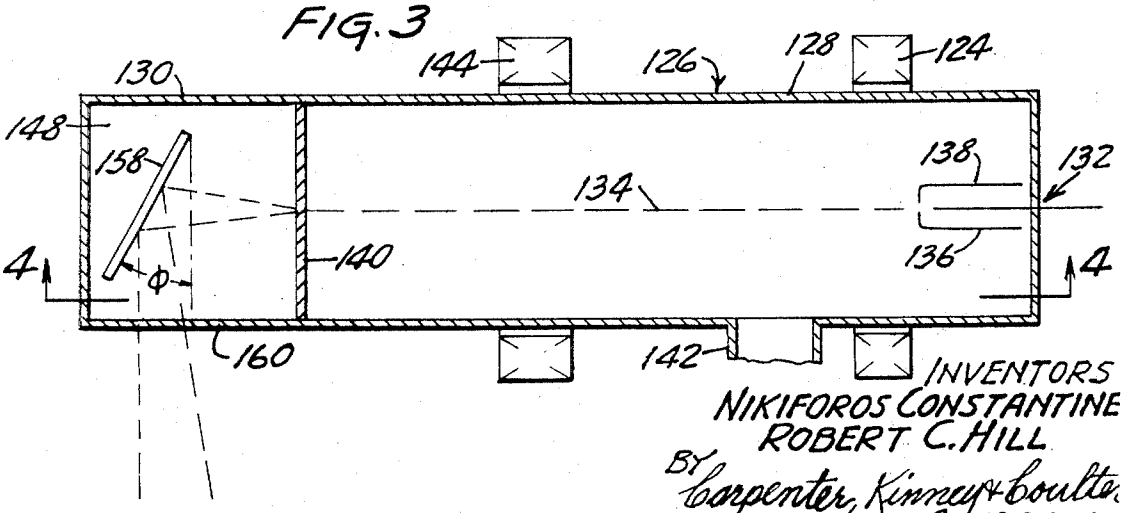



FIG. 3




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FIG. 4

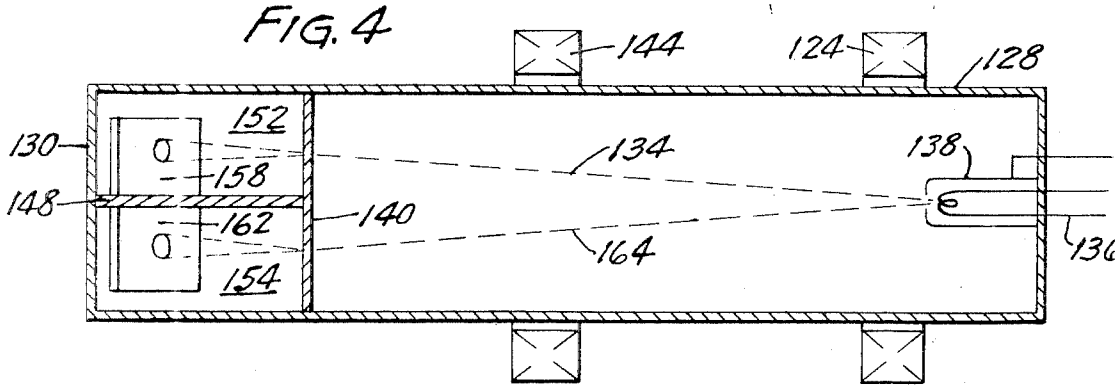



FIG. 6A

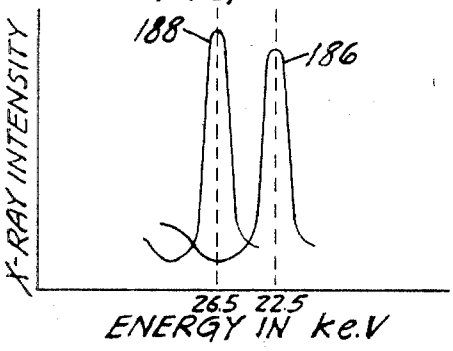



FIG. 6C

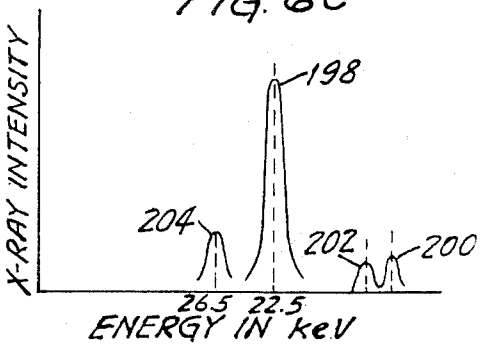



FIG. 6B

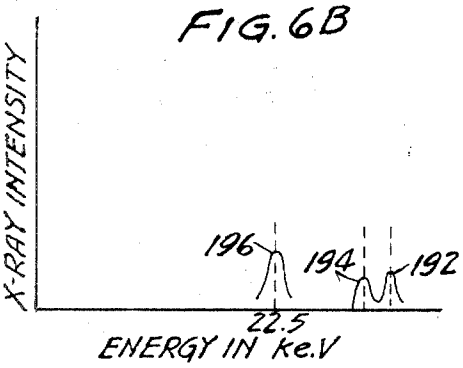



FIG. 6D

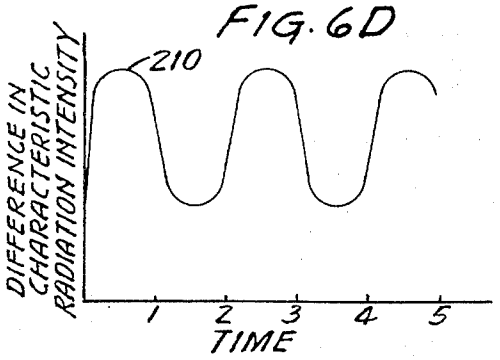



FIG. 7

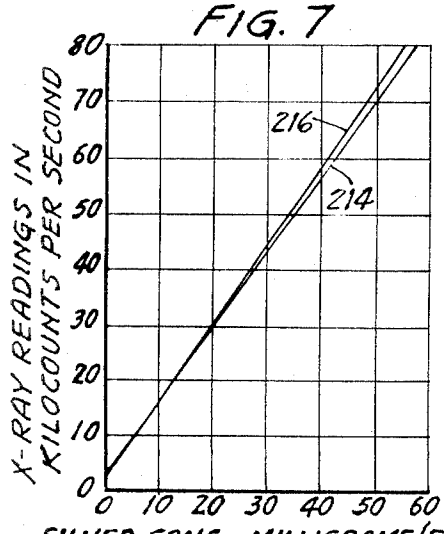



FIG. 5A

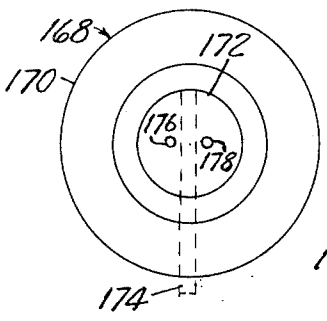
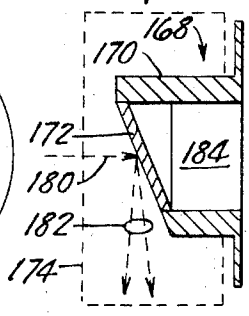



FIG. 5B




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3,525,863

# DIFFERENTIAL EMISSION X-RAY GAUGING APPARATUS AND METHOD USING TWO MONOCHROMATIC X-RAY BEAMS OF BALANCED INTENSITY

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U.S. Cl. 250—51.5 22 Claims

## ABSTRACT OF THE DISCLOSURE

A differential emission X-ray gauging apparatus and method are shown wherein a dual X-ray beam source produces a first monochromatic X-ray beam having a wavelength which is slightly greater than the absorption edge of a selected element and a second monochromatic X-ray beam having a wavelength which is slightly less than the absorption edge of a selected element. Each of the X-ray beams is directed, for different periods, along a A detecting means positioned adjacent to and on the same localized area on a target containing the selected element. A detecting means positioned adjacent to and on the same side of the target receives flourescent characteristic radiation from the selected element, fluorescent characteristic radiation from other elements in the target and backscattered radiation and produces a modulated output signal derived from the difference in radiation, which output signal represents concentration of the selected element on the target.

X-ray gauging apparatus and methods utilizing fluorescent characteristic radiation emitted by a selected element from a target surface for measuring concentration of the element are well known. Certain of the fluorescent X-ray gauging apparatus and methods utilize a single X-ray beam and a single detector for mesuraing concentration of a selected element on a target surface. In a polychromatic X-ray gauging apparatus, a single polychromatic X-ray beam is used to irradiate a target surface containing the selected element. The selected element emits fluorescent characteristic radiation which is received by a detector located on the same side of the target surface as the source. A source filter, that is a filter inserted between the X-ray source and the surface being irradiated, attenuates the relatively low energy portion of the primary X-ray beam. For example, such filters typically are brass. Also, a detector filter, that is a filter which is inserted into the radiation emitted from the surface of the target being measured, between the target and the detector, selectively transmits the characteristic radiation of the selected element with a minimum attenuation and all other radiation with a greater attenuation. By detecting the maximum radiation intensity or radiation counts associated with the fluorescent characteristic radiation, the concentration of the selected element can be determined.

Another single beam fluorescent X-ray gauging apparatus and method utilizes a single beam monochromatic source. In this type of apparatus, the X-ray source generates a single polychromatic X-ray beam which irradiates a secondary emitter. The secondary emitter is selected to be an element which, when excited by the polychromatic X-ray beam for generating a monochromatic X-ray beam having a wavelength capable of exciting the element being gauged, emits fluorescent characteristic radiation. The monochromatic X-ray beam is directed along a predetermined path to irradiate the target surface producing fluorescent characteristic radiation from the selected element and fluorescent characteristic radiation from all other elements present in the target having a wavelength which is greater than that of the monochromatic X-ray beam. A detector, having a detector filter inserted between the target surface and the detector, is located on the same side of the target surface as the X-ray source and receives the characteristic radiations and backscattered radiation. The detector filter is selected to be of an element which selectively transmits the fluorescent characteristic radiation from the selected element with minimum absorption and fluorescent characteristic radiation from all other elements and backscattered radiation with a greater amount of absorption.



Both of the single beam fluorescent X-ray gauging apparatus and methods utilize a detector filter to enhance the signal-to-noise ratio of the detected signal. However, the counting rates and the intensity of the fluorescent characteristic radiation are a direct function of the kev. and intensity of the primary X-ray beam incident upon the target surface.

Each of the above X-ray fluorescent gauging apparatus and methods has several inherent disadvantages. In particular, the prior art devices gauge or measure large concentrations of a selected element in a coating on a supporting layer or of a selected element dispersed in a matrix. However, the prior art devices cannot be used to accurately gauge or measure small concentrations of a selected element located in a coating or dispersed in a matrix. Further, any variances in the supporting layer or matrix thickness or composition seriously affect the gauging accuracy.

In the prior art gauging apparatus and methods, the total fluorescent characteristic radiation from the selected element and other elements in the coating and supporting layer or from the other elements in the matrix and backscattered radiation from the exciting beam is used for measuring concentration of the selected element. However, the backscattered radiation, which is part of the total radiation ultimately detected by the prior art apparatus and methods, varies as a function of the variance in the supporting layer and matrix. Thus, any changes in the supporting layer or matrix thickness or composition affect the total radiation count received by the detector and subsequently the accuracy in gauging the concentration of the selected element. Thus, prior art gauge apparatus and methods are dependent upon the thickness and chemical composition of the supporting layer or matrix being relatively constant.

In certain prior art methods, effects of variance in the supporting layer or matrix are reduced by employing filters which minimize the effects of the backscattered radiation. However, as the concentration of the selected element being measured decreases, the signal-to-background ratio for a filter becomes extremely poor. Thus, at low concentrations, the prior art methods become very inaccurate.

In the prior art, compensation of background noise and characteristic radiation from other than a selected element is accomplished by two known methods: namely, Kustner's method and Ross' method. Kustner's method may or may not utilize a source filter and a detector filter in a manner similar to the single beam polychromatic gauging apparatus and method. However, an additional filter is sequentially placed first between the source filter and the target surface and then between the target surface and the detector filter. This filter is selected to be a material or an element which strongly attenuates the fluorescent characteristic radiation emitted from the selected element contained within the target surface being analyzed and one which, at the same time, does not readily attenuate the X-ray source beam. By use of this additional filter, the magnitude of the background

radiation can be better determined and subtracted from the total radiation. The difference between total radiation and background radiation is representative of fluorescent characteristic radiation from the selected element.

Ross' method also uses a single polychromatic X-ray beam. However, a source filter and a detector filter are eliminated and replaced by a pair of balanced filters which are sequentially inserted between the target and the detector. The balanced filters function as separate detector filters.

The thickness of each filter is adjusted such that the absorption of radiation at all wavelengths, except at the wavelengths of the characteristic radiation of the selected element being gauged, is substantially the same. In addition, one of the filters is selected so as to attenuate or absorb the selected element characteristic radiation while the other filter transmits the selected element characteristic radiation with little absorption.

The difference between the radiation counts selectively transmitted by each of the filters to the detector is the intensity of the fluorescent characteristic radiation of the selected element.

One main disadvantage of Kustner's method is that a relatively large amount of electrical power is required to generate a primary X-ray beam having sufficient intensity to pass through each of the filters selectively inserted into the radiation. One primary disadvantage of Ross' method is that balancing of the two filters is quite difficult. Further, the applicability of using the balanced filter technique is limited by the number of suitable elements available to be used by a filter together with the difficulty of fabricating filters of desired elements or materials.

Additional problems are encountered if the above known methods are used for on-line, non-destructive measurements or gauging. Both known methods require mechanical positioning apparatus for precisely positioning the filters. Since the filters are mechanically positioned, the time constant for making each measurement is significantly increased to provide sufficient time for the filters to be positioned and then settled in position.

The differential emission X-ray gauging apparatus and method of the present invention overcomes the disadvantages associated with the prior art apparatus and methods. In the present invention, a dual beam monochromatic X-ray source is utilized. One of the monochromatic X-ray beams is selected to have a wavelength which is slightly greater than the absorption edge wavelength of a selected element to be measured while the other monochromatic X-ray beam is selected to have a wavelength which is slightly less than the absorption edge wavelength of the selected element. The monochromatic X-ray beams separately irradiate substantially the same localized area of the target containing the selected element. The monochromatic X-ray beam having a wavelength slightly less than that of the selected element excites the selected element and other elements of lower atomic number to fluorescence emitting fluorescent characteristic radiation. The other monochromatic X-ray beam having the slightly greater wavelength is balanced relative to the one monochromatic X-ray beam and excites other elements to the same extent, but not the selected element, to fluorescence emitting characteristic radiation. A detector, which may or may not have a detector filter, is positioned adjacent to and on the same side of the target as the monochromatic X-ray beams and receives the selected element and other elements fluorescent radiation and backscattered radiation from each of the monochromatic X-ray beams. The detector electrically determines the difference in radiation received in response to each of the monochromatic X-ray beams and produces a modulated output signal. The output signal represents the concentration of the selected element on a target surface.

The differential emisison X-ray gauging apparatus and method of the present invention represents a substantial improvement over prior art devices. For example, in the present invention no heavy filtering of the X-ray beams is necessary. Therefore, the power requirements of the monochromatic X-ray beams are substantially less than that required for prior art X-ray gauging apparatus and methods for gauging low concentrations of selected elements for the same accuracy and supporting layer thickness. The differential emission X-ray gauging apparatus and method of the present invention teaches a unique and novel non-dispersive fluorescent X-ray gauging technique. The apparatus and method of the present invention is capable of measuring low concentration of a selected element on a target relatively independently of base, supporting layer or matrix changes at relatively fast counting rates. Since lower power or lower intensity monochromatic X-ray beams are utilized, the saturation of detectors or counters by the resulting fluorescent characteristic radiation and backscattered radiation is eliminated.

In one embodiment, a detector filter is inserted between the target and the detector to further increase the signal-to-noise ratio of the detected radiation. The detector filter is selected to be an element which selectively transmits the selected element fluorescent characteristic radiation with substantially little absorption and the other elements fluorescent characteristic radiation or background radiation and backscattered radiation with greater absorption.

One advantage of the present invention is that required output power levels or intensity levels of the monochromatic X-ray beams are greatly reduced compared to prior art devices.

An additional advantage of the differential emission X-ray gauging apparatus of the present invention is that measurements of the concentration of selected elements in a coating on a base material in one embodiment can be attained at relatively high counting rates at short time constants resulting in at least a one percent statistical accuracy at a 95 percent confidence level.

Another advantage of the present invention is that a novel and unique method for measuring the concentration of a selected element on a target relatively independent of changes in the base material or matrix is possible by using two monochromatic X-ray beams each having a different predetermined wavelength.

Yet another advantage of the differential emission X-ray gaughing apparatus and method of the present invention is that a filter may be used to increase the signal-to-noise ratio of the selected element fluorescent characteristic radiation to background radiation and backscattered radiation received by the detector.

These and other advantages of the present invention will become apparent when considered in light of the detailed description of the preferred embodiment taken together with the drawing wherein:

FIG. 1 is a pictorial representation of one embodiment of the present invention illustrating a differential emission X-ray gauging apparatus which is capable of practicing the method of this invention;

FIG. 2 is a diagrammatic representation of one embodiment of an X-ray source capable of utilizing a mechanical chopper to generate monochromatic X-ray beams for practicing this invention;

FIG. 3 is a diagrammatic representation of a preferred embodiment of an X-ray source utilizing an electron beam which is deflected between adjacent outer surface areas on a transmission anode for generating monochromatic X-ray beams for practicing this invention;

FIG. 4 is a section taken along line 4—4 in FIG. 3 illustrating in greater detail the transmission anode structure of FIG. 3;

FIGS. 5A and 5B are a front view and a cross-sectional view respectively of a reflective anode which permits use of high current density electron beams;

FIG. 6A is a graph illustrating X-ray intensity plotted as a function of wavelength depicting the characteristics of one monochromatic X-ray beam having a characteristic wavelength which is slightly shorter than the absorption edge wavelength of a selected element and another monochromatic X-ray beam having a characteristic wavelength which is slightly longer than the absorption edge wavelength of a selected element;

FIG. 6B is a graph illustrating X-ray intensity plotted as a function of wavelength depicting background fluorescent characteristic radiation emitted from other elements having a wavelength which is greater than the absorption edge of a selected element and backscattered radiation produced in response to the target being irradiated by the other monochromatic X-ray beam having a wavelength which is slightly longer than the absorption edge of the selected element;

FIG. 6C iis a graph illustrating X-ray intensity plotted as a function of wavelength depicting the fluorescent characteristic radiation emitted by a selected element from a target surface, background fluorescent characteristic radiation emitted from other elements having a wavelength which is less than the absorption edge of the selected element and backscattered radiation in response to the target being irradiated by one monochromatic X-ray beam having a wavelength which is slightly shorter than the absorption wavelength of a selected element;

FIG. 6D is a graph illustrating the fluorescent characteristic radiation counts received by a detector in response to each monochromatic beam plotted as a function of time; and

FIG. 7 is a graph of X-ray reading plotted as a function of silver concentration on base layers of different thicknesses for a differential emission gaughing apparatus.

Briefly, a differential emission X-ray gaughing apparatus of the present invention includes a means for generating a first monochromatic X-ray beam having a wavelength which is at least slightly greater than the absorption edge of a selected element and a second monochromatic X-ray beam having an intensity which is balanced with respect to that of the first beam and having a wavelength which is slightly less than the absorption edge of the selected element. Means operatively coupled to the generating means are provided for directing the first monochromatic X-ray beam along a first predetermined path to irradiate a localized area on a target containing the selected element and the other elements in the target having an absorption edge wavelength which is greater than the wavelength of the first monochromatic X-ray beam to emit fluorescent characteristic radiation and the second monocromatic X-ray beam along a second predetermined path to irradiate substantially the same localized area on the target at a period other than a period when the first monochromatic X-ray beam irradiates the target to excite the selected element and the other elements to emit fluorescent characteristic radiation. A detecting means is positioned adjacent to and on the same side of the target as the generating means. The detecting means receives the fluorescent characteristic radiation emitted from the selected element and from said other elements and produces a modulated output signal which is derived from the difference between the total radiation received in response to irradiation of the target by the first and second monochromatic X-ray beams wherein the magnitude of said modulated output signal represents concentration of the selected element.

A method for measuring concentration of a selected element on a target is also a part of the present invention. The method comprises the steps of generating a first monochromatic X-ray beam having a wavelength which is slightly greater than the absorption edge of a selected element; directing the first monochromatic X-ray beam along a first predetermined path to irradiate a localized area on a target containing the selected element; generating a second monochromatic X-ray beam having a wavelength which is slightly less than the absorption edge of the selected element exciting the other elements in the target having an absorption edge wavelength which is greater than the wavelength of said first monochromatic X-ray beam to emit fluorescent characteristic radiation; directing said second monochromatic X-ray beam along a second predetermined path to irradiate substantially the localized area on the target at a period other than a period when the first monochromatic beam irradiates the target exciting the selected element and the other elements to emit fluorescent characteristic radiation; balancing the intensity of the first and second monochromatic beams so that fluorescent characteristic radiation from the other elements and backscattered radiation from each of the monochromatic beams are substantially the same for each monochromatic X-ray beam; detecting by a detecting means positioned adjacent to and on the same side of the target as said first and second generating means the difference between radiation emitted from the selected element and from all elements of the target having an atomic number which is lower than that of the selected element and backscattered radiation from each of said monochromatic X-ray beams; and producing in response to the difference in radiation a modulated output signal representing concentration of the selected element.

FIG. 1 is a diagrammatic representation of the apparatus and method for carrying out the teachings of this invention for measuring the concentration of a selected element on a target.

The differential emission X-ray gauging apparatus illustrated in FIG. 1 includes a means for generating a first monochromatic X-ray beam having a wavelength which is at least slightly greater than the absorption edge of a selected element and a second means for generating a second monochromatic X-ray beam having a wavelength which is slightly less than the absorption edge of the selected element. In one embodiment, the X-ray gauging apparatus includes a source of electrons **10** for producing an electron beam **12**. The electron beam **12** is directed along a path to bombard a reflective anode **14** which is capable of generating a polychromatic X-ray beam in response to being bombarded by the electron beam **12**. For example, the anode may be tungsten. The electron beam **12** can be focused to a relatively thin cross-section, say in the order of $10\mu$, by a conventional focusing means, such as for example an electromagnetic focusing coil **16**. The electron beam **12** can be selectively deflected through an angle $\theta$ to bombard a different surface of the reflective anode **14**. The electron beam **12** can be selectively deflected by conventional beam deflecting devices, such as for example an electromagnetic deflecting coil **18**.

The reflective anode **14** has two slanting outer surfaces **22** and **24** which are alternatively bombarded by the electron beam **12**. When the slanting outer surface **22** is bombarded by the electron beam **12**, that surface emits a polychromatic X-ray beam **26** which is directed onto a secondary emitter **28**. Similarly, when the electron beam **12** bombards outer surface **24**, a second polychromatic X-ray beam **32** is generated therefrom and directed onto a second secondary emitter **34**. Normally, the electron gun used for the source of electrons **10**, the electron beam **12** and anode **14** are enclosed in an evacuated chamber having a window, such as for example beryllium, which permits the polychromatic X-ray beam to leave the evacuated chamber while preserving the vacuum condition in the chamber.

The first secondary emitter **28** is selected to be a material which, when irradiated by the first polychromatic X-ray beam **26**, radiates monochromatic characteristic X-ray radiation having a wavelength which is slightly greater than the absorption edge of a selected element. The selected element is contained within a target such as, for example, a first material **36** which is coated onto a second material, such as for example a supporting layer

38. A first monochromatic X-ray beam 40 is generated by the first secondary emitter 28 in response to the polychromatic X-ray beam 26. The first monochromatic X-ray beam 40 is directed along a first predetermined path to irradiate a localized area 44 on the coating layer 36 containing the selected element being monitored by the gauging apparatus.

The first monochromatic X-ray beam 40 excites the other elements in the target or coating layer 36 and supporting layer 38 having an absorption edge wavelength which is greater than the wavelength of the first monochromatic X-ray beam 40 to emit fluorescent characteristic radiation.

When the electron beam 12 is selectively deflected at an angle $\theta$ by the electromagnetic deflecting coil 18 onto the outer surface 24, the second polychromatic X-ray beam 32 irradiates the second secondary emitter 34 to generate a second monochromatic X-ray beam 46. The second monochromatic X-ray beam 46 is directed along a second predetermined path to irradiate substantially the same localized area 44 which was irradiated by the first monochromatic X-ray beam 40.

The second monochromatic X-ray beam 46 excites the selected element and the other elements in the coating layer 36 and the supporting layer 38 to emit fluorescent characteristic radiation.

The term fluorescent characteristic radiation as used herein is meant to include the secondary characteristic radiation emitted from elements at discrete wavelengths, such as for example the $K_{\alpha 1}$, $K_{\alpha 2}$, $K_{\beta 1}$ and $K_{\beta 2}$ characteristic lines. In practicing this invention, it may be desirable to select a predetermined one of the characteristic lines or to average radiation from certain of the lines. In other applications, it may be desirable to use lower order lines of radiation, such as for example the L lines. In any event, the term fluorescent characteristic radiation is contemplated to cover such uses of the characteristic emission lines.

The intensity of the monochromatic X-ray beams 40 and 46 may be adjusted by controlling the intensity of the polychromatic X-ray beams 26 and 32 which irradiate secondary emitters 28 and 34 respectively. The adjusting means may be, for example, a pair of wedges 48 and 50 which are interposed between the anode 14 and the secondary emitters 28 and 34 respectively. The wedges 48 and 50 are adjusted such that the fluorescent characteristic radiation of the lower atomic number elements in the coating and base layer produced in response to irradiation by each monochromatic X-ray beam and the back-scattered radiation from each of the monochromatic X-ray beams is substantially identical or balanced. When the fluorescent characteristic radiation from the other elements of lower atomic number and the backscattered radiation from each monochromatic X-ray beam are balanced, the difference in radiation produced from the coating and supporting layer in response to irradiation by each of the monochromatic X-ray beams is the fluorescent characteristic radiation from the selected element being monitored.

It is contemplated that the adjusting means may be any other known mechanical or electrical means for controlling intensity of the monochromatic X-ray beam. For example, the wedges may be positioned to intercept the monochromatic X-ray beams. Also, filters may be used to control monochromatic X-ray beam intensity. Alternatively, the electron beam current density may be modulated, by known means, as the electron beam bombards the anode 14.

A detecting means such as, for example, a radiation counter 52 is positioned adjacent to and on the same side of the target as the means for generating the first and second monochromatic X-ray beams. The detecting means or radiation counter 52 receives radiation emitted from the selected element within the coating layer 36 and from other elements of the target or coating layer 36 and supporting layer 38 having an atomic number which is lower than the selected element. The radiation counter 52 detects the total radiation received in response to irradiation of the coating layer 36 by the first and second monochromatic X-ray beams 40 and 46 and supplies electrical signals representing the radiation counts to an amplifier and output circuit 54. The amplifier 54 amplifies the electrical signals received from the radiation counter 52, and the output from the amplifier 54 is in the form of a modulated output signal derived from the difference between the total radiation received by the radiation counter 52 in response to irradiation of the coating layer 36 and supporting layer 38 by the first and second monochromatic X-ray beams 40 and 46 respectively. The magnitude of the modulated output signal represents the concentration of a selected element within the layer 36. If the coating layer 36 contains a predetermined concentration of selected element, the concentration of selected element in coating layer 36 may be used to monitor the thickness of the coating layer 36 on the supporting layer 38. The modulated output signal from the amplifier 54 may be applied to an output device 56 for displaying the concentration of the selected element.

If desired, the detector 52 may include a detector filter, similar to filter 88 in FIG. 2, for increasing the signal-to-background ratio. When the signal-to-background ratio is increased, the gauging range of the differential emission gauge may be extended for gauging relatively small concentrations of a selected element at short time constants. For example, in the absence of a filter, silver concentrations in the order of 10 mg./dm.$^2$ to 50 mg./dm.$^2$ on about a .005 inch (approximately .125 mm.) polyester base can be easily gauged. With a silver detector filter, silver concentrations on the same base ranging from about 1 mg./dm.$^2$ to about 10 mg./dm.$^2$ can be gauged with the same accuracy and time constants.

FIG. 2 is a pictorial representation of a mechanical beam switching device for producing two monochromatic X-ray beams for irradiating a coating layer 58 containing a selected element on a supporting layer 60. An electron gun, similar to electron source 10 of FIG. 1, is located within a vacuum-pumped electron gun chamber, shown generally as 68. An electron beam 70 is directed along a preselected path to bombard an outer surface of a reflective anode 72. The reflective anode 72 is capable of generating a polychromatic X-ray beam, generally shown by shaded area 74, having a peak wavelength at a wavelength which is shorter than that of the selected secondary emitters. The polychromatic X-ray beam 74 passes through a collimating means, generally designated as 76, including a cylindrical tube member 78 which directs the polychromatic X-ray beam 74 into a rectangular-shaped housing 80. The housing 80 has one end surface 82 which communicates with a radiation detector 84 through an opening 86 located in the end surface 82. A detector filter 88 is positioned within opening 86 to selectively transmit the fluorescent radiation to the detector 84.

A triangular-shaped end 90 is located at the opposite end of the housing 80 relative to the end surface 82 and has therein an opening 92 through which X-ray beams generated within the housing 80 irradiate the coating layer 58 containing the selected element on supporting layer 60.

The collimating means 76 includes a shielding member 96 which is located in the lower portion of housing 80. The shielding member 96 is substantially parallel to and spaced from the bottom surface of the housing 80 and is substantially perpendicular to the end surface 82. The shielding member 96 has two openings 98 and 100 located just below the cylindrical tube member 78. The openings 98 and 100 are located in a spaced relationship relative to each other and just below the cylindrical tube member 78 such that a portion of the polychromatic X-ray beam 74 directed onto one side of the shielding member 96 will pass therethrough into the lower portion of the hous-

ing **80** when the openings **98** and **100** are selectively uncovered.

A pair of secondary emitters **110** and **112** are positioned on the opposite side of the shielding member **96** relative to the collimating means **76** including cylindrical tube member **78**. The secondary emitters **110** and **112** are positioned in alignment with apertures **98** and **100** respectively.

One of the secondary emitters, such as secondary emitter **110**, is selected to be a material which will generate fluorescent radiation having a wavelength which is slightly greater than that of the absorption edge of the selected element contained within coating layer **58** which is to be monitored by the apparatus. The other of the secondary emitters, secondary emitter **112**, is selected to be a material which produces fluorescent radiation having a wavelength which is slightly less than that of the absorption edge of the selected element.

When the polychromatic X-ray beam **74** passes through aperture **98**, the fluorescent characteristic radiation from the first secondary emitter **110** is used as a first monochromatic X-ray beam having a wavelength which is slightly greater than that of the selected element. The first monochromatic X-ray beam passes through opening **92** to irradiate the coating layer **58**. The elements in coating layer **58** and supporting layer **60** having an atomic number which is less than that of the selected element will generate the fluorescent characteristic radiation. The fluorescent radiation generated from the coating layer **58** and supporting layer **60** is detected by radiation detector **84**. The filter **88** positioned in the opening **86** functions to selectively transmit the fluorescent characteristic radiation from the selected element with slight absorption and the fluorescent characteristic radiation from other elements or lower atomic number than the selected element and backscattered radiation from the exciting monochromatic X-ray beam with substantial absorption.

When the polychromatic X-ray beam **74** passes through aperture **100**, the fluorescent characteristic radiation from the second secondary emitter **112** is used as the second monochromatic X-ray beam having a wavelength which is slightly less than that of the selected element. The selected element in coating layer **58** and the other elements in both the coating layer **58** and supporting layer **60** generate fluorescent characteristic radiation which is selectively transmitted by filter **88** and received by radiation detector **84** in a manner similar to that for the first monochromatic X-ray beam.

Means, such as for example a mechanical chopper wheel **102**, may be positioned on one side of the shielding member **96** and relative to the apertures **98** and **100** for alternately blocking the apertures to permit the polychromatic X-ray beam to pass through one of the apertures to generate only one monochromatic X-ray beam at a time.

The mechanical chopping wheel **102** is rotatably supported to be rotated at a relatively high r.p.m. The mechanical chopper wheel **102** has a plurality of blades **106**, such as for example 16 blades, which are spaced apart a predetermined distance equal to the predetermined spacing between apertures **98** and **100**. The spacing between the mechanical chopper blades **106** should be substantially equal to the width of each of the individual blades **106**. The blades **106** are rigidly connected to a hub **108** and extend from the hub **108** a sufficient length so as to cover at least one of the openings **98** or **100** at any time. Thus, when a blade **106** is located between the tubular member **78** and opening **100**, only opening **98** permits a portion of the polychromatic X-ray beam **74** to pass therethrough. Similarly, when the hub **108** advances the blades **106** such that the opening **98** is covered by one of the blades **106**, opening **100** then has the polychromatic X-ray beam **74** passing therethrough.

When the chopper blades **106** are rotated to a position wherein an aperture **98** or **100** is covered by a chopper blade **106**, the unblocked aperture permits the polychromatic X-ray radiation to pass therethrough to cause its associated secondary emitter **110** and **112** respectively to emit its fluorescent characteristic radiation. The fluorescent characteristic radiation passes through opening **92** to irradiate the localized area on the coating layer **58**. The resulting fluorescent characteristic radiation of the selected element, characteristic fluorescent radiation from other elements in the coating layer **58** and supporting layer **60** and backscattered radiation are selectively transmitted by filter **88** and subsequently passed through the radiation detector **84**. The radiation detector **84** then produces a modulated output signal which is derived from the difference between the total irradiation produced from the localized area on the coating layer **58** in response to each of the monochromatic X-ray beams. The magnitude of the modulated output signal produced by the detector **84** represents the concentration of the selected element in coating layer **58**.

In one embodiment, the mechanical switching means or chopper well **102** is formed of a metal which substantially attenuates a portion of the polychromatic X-ray beam **74** in the region in which it is required to cause the secondary emitter to emit fluorescent radiation. The chopper wheel **102** is constructed of brass and has thereon a total of 16 blades equally spaced. The width of each of the blades and the spacing between blades is selected to equal the center distance between the two apertures **98** and **100**. The secondary emitter **110** is selected to be silver and the secondary emitter **112** is selected to be antimony. The apparatus and method is used for measuring the concentration of silver in a coating applied to a supporting layer, such as a polyester material.

In one gauging operation, the chopper wheel **102** is rotated at 3600 r.p.m. and the thickness of the secondary emitters **110** and **112** is selected so that substantially the same irradiation is received by the radiation detector **84** when only a base material or supporting layer **60** is irradiated. When this occurs, the modulated output signal from the radiation counter is substantially a zero signal or a minimum A.C. modulated signal.

A coating layer **58** containing silver in concentrations ranging in the order of zero to about 50 mg./dm.$^2$ is capable of being monitored by the differential emission gauging apparatus. A photomultiplier is used as the radiation detector **84** and the output from the photomultiplier is amplified by means of an amplifier **118**. The amplified signal is passed through a filter **120** having a 700–1100 cycle/second bandwidth. The output of filter **120** is modulated with an A.C. meter **122**. When the output of the A.C. meter **122** is plotted as a function of silver density in mg./dm.$^2$, the resulting graph is a substantially linear curve or a straight line.

FIG. 3 is yet another embodiment of a means for generating the monochromatic X-ray beams. In the embodiment illustrated in FIG. 3, the dual monochromatic X-ray beams are obtained by switching the electron beam between predetermined areas on a transmission anode. In particular, an electron gun housing, generally designated **126**, includes an electron gun chamber **128** and a radiation chamber **130**. The electron gun chamber **128** encloses an electron gun assembly **132** which is operatively connected to appropriate filament supplies, grid supplies and the like (not shown). The electron gun assembly **132** includes a filament **136** which is supplied filament current from a conventional filament current supply. A grid **138** having an aperture at the end thereof is electrically connected to the filament **136**. In this embodiment, electrons from the filament **136** are formed into an electron beam of uniform diameter by the aperture in grid **138**. The electron beam of uniform diameter is focused into an electron beam of desired cross-section by a focusing means, such as for example a focusing coil **124**. The focused electron beam **134** is directed along a predetermined path to alternately bombard separate outer surface areas of a transmission anode **140** located at the opposite

end of the electron gun chamber **128**. Vacuum is maintained in the electron gun chamber **128** by means of a vacuum pump (not shown) operatively connected to the chamber **128** through conduit **142**. Alternatively, it is contemplated that the entire electron gun chamber may be a sealed tube having a desired vacuum.

The electron beam **134** is alternately deflected between the separate outer surface areas of the transmission anode **140** by a means for deflecting the electron beam, such as an electromagnetic deflection coil **144**. Each of the outer surface areas of transmission anode **140** produces a polychromatic X-ray beam having a peak wavelength at a wavelength which is shorter than that of the selected two secondary emitters. In one embodiment, the X-ray yield from the transmission anode **140** is increased by using an approximately .010 inch (approximately .254 mm.) copper sheet having an approximately .0002 inch (approximately 12$\mu$) gold coating.

The transmission anode **140**, when selectively bombarded by the electron beam **134**, generates a polychromatic X-ray beam within the radiation chamber **130**. The radiation chamber **130** is divided into two sections by means of an X-ray impervious shield, such as for example a shield **148**.

FIG. 4, which is a section taken along line **4—4** of FIG. 3, illustrates the construction of the radiation chamber **130** showing particularly the relationship between the two separate chamber sections **152** and **154**. Secondary emitters **158** and **162** are mounted in each chamber section **152** and **154**. The secondary emitters are generally in the form of a thin sheet-like construction mounted on the shield **148** in a spaced relationship from the transmission anode **140**.

For example, in chamber **152** the secondary emitter **158** is securely attached to the shield **148** and is positioned at an angle $\phi$ so as to direct the fluorescent characteristic radiation emitted by the secondary emitter **158** through an opening **160** onto the target containing the selected element to be measured.

Similarly, the other secondary emitter **162** is rigidly mounted to the shield **148** in the other chamber section **154**. The secondary emitter **162** is mounted at an angle $\phi$ relative to the transmission anode **140** in a manner similar to that for the secondary emitter **158**.

In FIG. 4, the electron beam **134** is shown being deflected onto one outer surface area of the transmission anode **140** which is adjacent the first chamber section **152**. The alternate position of the electron beam **134** is illustrated by dashed line **164** which represents the second predetermined path along which the electron beam **134** is alternately deflected onto the other outer surface area of the transmission anode **140**.

The means for deflecting the electron beam **134** between the outer surface areas of transmission anode **140**, or in this embodiment the electromagnetic deflection coil **144**, is controlled by deflection signals. The deflection signals may be obtained from a source of deflection signals operatively coupled to the deflecting means or coil **144** for programming the deflection coil. The deflection signals may be derived from a bi-level voltage device, such as a flip-flop. The deflection signals program deflecting the electron beam to a predetermined one of the outer surface areas and control the dwell time of the deflected electron beam on the predetermined outer surface area.

FIGS. 5A and 5B are frontal and sectional views respectively of a reflective anode **168**. Reflective anode **168** can be used in place of the transmission anode **140** in FIGS. 3 and 4. In particular, the anode **168** comprises a cylindrical support **170** which supports a disk **172** capable of being bombarded by an electron beam to produce a polychromatic X-ray beam. In one embodiment, the support **170** comprised copper and supported a disk **172** comprising tungsten. The reflective anode **168** is divided into two separate isolated areas such as, for example, by a shielding means illustrated by dashed shield **174**. The disk **172** is alternately bombarded by an electron beam in localized areas designated as **176** and **178** in FIG. 5A. In FIG. 5B, the electron beam, designated by arrow **180**, bombards the disk **172** causing polychromatic X-ray radiation which is emitted in a direction designated by dashed arrows **182**. When reflective anode **168** is utilized, the secondary emitters for separately generating monochromatic X-ray beams are located below and in alignment with the disk **172** and on each side of shield **174** to receive the polychromatic beams illustrated by arrows **182** emanating from each localized area **176** and **178**. An inner area **184** of the reflective anode **168** is ported and sealed such that a liquid coolant, for example water, can be passed therethrough maintaining the reflective anode at a desired ambient temperature.

The reflective anode **168** when water cooled is capable of being continuously irradiated by an electron beam having a power intensity in the order of about 6500 watts/cm.$^2$. In some applications, the reflective anode **168** is capable of being bombarded by an electron beam having a power intensity up to and in excess of approximately 12 kw./cm.$^2$. Generally, tranmission anode **140**, of FIGS. 3 and 4, is limited to radiation by an electron beam having a power intensity in the order of about 3000 watts/cm.$^2$.

Referring momentarily back to FIGS. 3 and 4, the differential emission X-ray gauging apparatus, in one embodiment, was employed for measuring the concentration of silver in a coating on a supporting layer wherein the silver had concentrations ranging in the order of from 10–50 mg./dm.$^2$ and wherein the supporting layer was on a polyester base. Since the selected element in this embodiment was silver, the secondary emitter **158** was selected to be silver which would produce a monochromatic X-ray beam having a wavelength which was slightly less than the absorption edge of the selected element silver. The other secondary emitter **162** was selected to be antimony. The monochromatic X-ray beam produced by the secondary emitter **162** had a wavelength which was slightly less than that of the absorption edge of the selected element.

For purpose of example, the following table sets forth typical elements which could be gauged by using the apparatus and method of the present invention. The wavelength of the selected monochromatic X-ray beam is selected to excite at least the $K_{\alpha 1}$ characteristic lines of the selected element. As is known in the art, a monochromatic X-ray beam generated at the same wavelength as the selected element $K_{\alpha 1}$ wavelength will not excite the same to fluorescence.

| Element | Atomic No. | Absorption edge (A.) | $K_{\alpha 1}$ (A.) | 1st secondary emitter | | 2nd secondary emitter | |
|---|---|---|---|---|---|---|---|
| | | | | Element | $K_{\alpha 1}$ | Element | $K_{\alpha 1}$ |
| Chromium | 24 | 2.0701 | 2.290 | Chromium (Cr) | 2.290 | Iron (Fe) | 1.936 |
| Iron (Fe) | 26 | 1.7433 | 1.936 | Iron (Fe) | 1.936 | Nickel (Ni) | 1.658 |
| Zinc (Zn) | 30 | 1.2833 | 1.435 | Zinc (Zn) | 1.435 | Germanium (Ge) | 1.254 |
| Bromine (Br) | 35 | .920 | 1.040 | Bromine (Br) | 1.040 | Strontium (Sr) | .875 |
| Silver (Ag) | 47 | .4858 | .559 | Silver (Ag) | .559 | Antimony (Sb) | .470 |
| Tin (Sn) | 50 | .4247 | .491 | Tin (Sn) | .491 | Barium (Ba) | .395 |

If the element selected for the secondary emitter is not available in a foil or solid form, an oxide of the selected element or the element itself may be dispersed in an organic or other low atomic number matrix. Also, in certain applications where the atomic number of the

selected element is substantially greater than or less than the atomic number of other elements in the target, the secondary emitter element for both emitters having lower and higher wavelengths can be chosen to be elements which have a wide variance in wavelength relative to the absorption edge of the element. In the above table, the secondary emitter elements could be other elements depending upon the application and differences in atomic number between the selected element and other elements in the matrix or coating and base.

FIG. 6A is a graph representing the X-ray intensity plotted as a function of energy in kev. for one of the monochromatic X-ray beams which is produced by the electrical switching X-ray generating apparatus of FIGS. 3 and 4. Curve **186** of FIG. 6A illustrates the intensity and kev. of the first monochromatic X-ray beam produced by the silver secondary emitter **158**. Curve **188** represents the intensity and kev. of the monochromatic X-ray beam generated in response to the antimony secondary emitter **162**. The monochromatic X-ray beam peaks at about 26.5 kev. and has sufficient energy to excite the selected element. In this example, the selected element is silver having a characteristic fluorescent radiation wavelength at approximately 22.5 kev. or .55 A. Also, the elements having an atomic number which is lower than that of the selected element are excited to emit their characteristic radiation.

FIG. 6B is a plot of the X-ray intensity as a function of energy in kev. of the radiation received by a radiation counter in response to the first monochromatic X-ray beam which has a wavelength slightly greater than that of the selected element. Curves **192** and **194** represent the radiation from other elements of lower atomic number than the selected element. Curve **196** represents the backscattered radiation from the first monochromatic X-ray beam produced from the silver secondary emitter **158**.

FIG. 6C is a plot of the X-ray intensity plotted as a function of energy in kev. of the radiation received by a detector in response to the second monochromatic X-ray beam or the X-ray beam produced by the antimony secondary emitter **162**. In FIG. 6C, there is a relatively high peak intensity line **198** which occurs around 22.5 kev. The magnitude or peak amplitude of the radiation occurring at 22.5 kev. is directly proportional to the concentration of silver in the coating being monitored. The other peaks designated as **200** and **202** represent characteristic radiation from other elements of lower atomic number than that of the selected element while curve **204** represents the backscattered radiation due to the second monochromatic X-ray beam.

The intensity of the backscattered radiation is balanced to be at the same intensity level. The backscattered radiation intensity level can be controlled by varying the thickness of the secondary emitters used for generating the monochromatic X-ray beams. Alternately, the intensity of the polychromatic beams impinging on the secondary emitters can be controlled through the use of wedges and the like as described hereinbefore. Thus, the radiation detector may have the minimum level of radiation set at the total radiation received in response to the first monochromatic X-ray beam and by measuring the total radiation which exceeds the reference radiation level in response to the second monochromatic X-ray beam, the difference therebetween represents the radiation intensity due to the selected element. The radiation intensity due to the selected element for small concentrations is directly proportional to the magnitude or concentration of the selected element on the first material or coating layer.

FIG. 6D is a graph illustrating a modulated output signal derived from the difference in characteristic radiation intensity plotted as a function of time. The time intervals are related to the switching times of either a mechanical switching system or an electrical switching system. Waveform **210** varies between a maximum amplitude and a minimum amplitude and the difference therebetween represents the intensity of the characteristic radiation from the selected element. The difference in radiation is substantially independent of variances in the base layer or matrix and represents substantially the fluorescent characteristic radiation from the selected element. The modulated electrical signal is applied to an output device which is calibrated to have the magnitude of the difference between the total irradiation due to each of the monochromatic X-ray beams converted directly into units representative of the concentration of the selected element. In this manner, the variance in the concentration of the selected element and the coating can be directly monitored in percentage of variations and the like.

In testing the capability of the differential emission X-ray gauging apparatus, silver samples with concentrations ranging from 10–15 mg./dm.$^2$ on a polyester base were utilized as test samples. In one experiment, the mechanical switching apparatus of FIG. 2 was utilized as the means for generating the first and second monochromatic X-ray beams. The X-ray beam had a power input of 10 milliamps at 50 kv. The radiation intensity was measured by taking the difference between the total radiation derived from irradiating the film having the silver coating with characteristic radiation of antimony and then with characteristic radiation of silver. The measuring of the concentration of the selected element was carried out both with and without a silver detector filter.

The graph of FIG. 7 is a plot of the X-ray readings representing the difference in X-ray counts received by the detector from each of the monochromatic X-ray beams in kilocounts per second plotted as a function of silver concentration in mg./dm.$^2$. Curve **214** of FIG. 6 depicts counts from samples coated on approximately a .005 inch (approximately .127 mm.) polyester base. Curve **216** of FIG. 6 depicts radiation counts from samples coated on approximately a .010 inch (approximately .254 mm.) polyester base. From the two curves **214** and **216**, two important relationships are illustrated. Firstly, the radiation counts of the selected element are substantially identical even though the base layer varied in thickness by 100 percent. Secondly, it is apparent that there is a substantially linear relationship between the difference in X-ray readings for various silver concentrations. Thus, by monitoring the difference in radiation intensity, the concentration of silver in the film can be very precisely measured relatively independent of variance in the base layer.

By inserting a silver detector filter having a thickness of approximately .002 inch (approximately .05 mm.), the signal-to-noise ratio at the minimum power level and a low selected element concentration were increased.

The present invention has wide utility as a non-destructive gauging apparatus. For example, the X-ray fluorescent gauge of the present invention may be used for on-line, non-destructive gauging of photographic film with short counting times or time constants without physically affecting or fogging the film.

It is apparent that the differential emission gauging apparatus and method of the present invention can be used for measuring a wide variety of selected elements contained within a coating layer on a supporting layer. It is anticipated that all such applications, uses and modifications and equivalents thereof which incorporate the teachings of the present invention are deemed to be within the scope of the appended claims.

What is claimed is:

**1.** A differential emission X-ray gauging apparatus comprising

means for generating a first monochromatic X-ray beam having a wavelength which is at least slightly greater than the absorption edge of a selected element and a second monochromatic X-ray beam having an intensity which is balanced with respect to that of said first beam and having a wavelength which is slightly less than the absorption edge of said selected element;

means operatively coupled to said generating means for directing said first beam along a first predetermined path to irradiate a localized area on a target containing said selected element and other elements having an absorption edge wavelength which is greater than the wavelength of said first beam to excite said other elements to emit fluorescent characteristic radiation and for directing said second monochromatic beam along a second predetermined path to irradiate substantially said localized area on said target at a period other than a period when said first monochromatic beam irradiates said target to excite said selected element and said other elements to emit fluorescent characteristic radiation; and

detecting means positioned adjacent to and on the same side of said target as said generating means for receiving said fluorescent characteristic radiation emitted from said selected element and from said other elements for producing a modulated output signal derived from the difference between the total radiation received in response to irradiation of said target by said first monochromatic X-ray beam and said second monochromatic X-ray beam wherein the magnitude of said modulated output signal represents concentration of said selected element.

**2.** The apparatus of claim **1** wherein said detecting means includes

a radiation detector for receiving said total radiation and for producing said modulated output signal as an alternating electrical signal having a frequency determined by the periods said first monochromatic X-ray beam and said second monochromatic X-ray beam irradiate said target and a magnitude determined by the intensity of said selected element fluorescent characteristic radiation produced during the period said second monochromatic X-ray beam irradiates said target.

**3.** The apparatus of claim **2** wherein said detecting means further includes

a detector filter selected from a material having an absorption edge wavelength which selectively transmits to said detector said selected element fluorescent characteristic radiation with slight absorption and said other elements fluorescent characteristic radiation and backscattered radiation with great absorption to increase the ratio of said selected element fluorescent characteristic radiation of said other elements fluorescent characteristic radiation and backscattered radiation;

an amplifier operatively connected to said detector for amplifying said alternating electrical signal; and

an output device operatively connected to said amplifier and response to the magnitude of said alternating electrical signal for indicating concentration of said selected element on said target.

**4.** The apparatus of claim **1** wherein said first and second monochromatic X-ray beam generating means includes first and second secondary emitters formed of elements which are capable of being excited by a polychromatic X-ray beam to produce said first and second monochromatic X-ray beams at their selected wavelengths.

**5.** The apparatus of claim **4** wherein said generating means includes

electron beam means for generating and directing an electron beam along a preselected path;

an anode having an outer surface positioned along said preselected path and relative to said electron beam means to have said electron beam directed along said preselected path to bombard said outer surface, said outer surface being capable of producing a polychromatic X-ray beam for exciting said first and second secondary emitters respectively to produce said first and second monochromatic beams; and

means positioned relative to said anode and responsive to said polychromatic X-ray beam for alternately irradiating said first and second secondary emitters to produce said first monochromatic X-ray beam and said second monochromatic X-ray beam which is directed onto substantially the same localized area of said target.

**6.** The apparatus of claim **5** wherein said anode has two separate outer surface areas adapted to be alternately bombarded by said electron beam, said apparatus further including

deflecting means positioned adjacent said preselected path and between said electron beam means and said anode for alternately directing said electron beam from one of said outer surface areas to the other of said outer surface areas to produce from each outer surface area a polychromatic X-ray beam for exciting said first and second emitters respectively to produce said first and second monochromatic X-ray beams.

**7.** The apparatus of claim **6** wherein said anode is a transmission anode having said separate outer surface areas in a spaced relationship on said transmission anode outer surface and wherein said deflecting means comprises

a magnetic deflection coil responsive to deflection signals for deflecting said electron beam between said outer surface areas on said transmission anode; and

a source of deflection signals operatively coupled to said deflection coil for programming said deflection coil to deflect said electron beam to a predetermined one of said outer surface areas and for controlling the dwell time of said deflected electron beam on said predetermined outer surface area.

**8.** The apparatus of claim **6** wherein said anode is a reflective anode having separate outer surface areas in a spaced relationship on said reflective anode outer surface and wherein said deflecting means comprises

a magnetic deflection coil responsive to deflection signals for deflecting said electron beam between said outer surface areas on said reflective anode; and

a source of deflection signals operatively coupled to said deflection coil for programming said deflection coil to deflect said electron beam to a predetermined one of said outer surface areas for controlling the dwell time of said deflected electron beam on said predetermined outer surface area.

**9.** The apparatus of claim **4** further including

collimating means including a shielding member having a pair of spaced apertures and positioned relative to said anode for directing said polychromatic X-ray beam onto one side of said shielding member and through an unblocked aperture;

said first and second secondary emitters each being positioned on the opposite side of said shielding member relative to said collimating means and in alignment with a different one of said apertures and capable of being irradiated by said polychromatic X-ray beam alternately passing through each of said apertures for generating said first and second monochromatic X-ray beams; and

means positioned on said one side of said shielding member and relative to said apertures for alternately blocking said apertures to permit said polychromatic X-ray beam to pass through one of the apertures to generate only one monochromatic X-ray beam at a time.

**10.** The apparatus of claim **9** wherein said alternately blocking means comprises

a chopper wheel having a hub and a plurality of spaced blades extending from said hub, said chopper wheel blades having a width and a spacing therebetween which are equal to the spacing between said pair of apertures, said chopper wheel being operative to alternately block one of said apertures with a blade while the other of said apertures remains unblocked and in alignment with the spacing between said

blades permitting said polychromatic X-ray beam to pass through said unblocked aperture; and

means operatively coupled to said chopper wheel to rotate said chopper wheel at a preselected number of revolutions per minute causing said blades to block and unblock said apertures to effectively switch said polychromatic X-ray beam between apertures to separately produce said monochromatic X-ray beams.

**11.** Apparatus adapted to measure a selected element in a sample by means of differential emission comprising

means for alternately irradiating said sample with a first and second monochromatic X-ray beam having a characteristic wavelength which is respectively slightly greater than and slightly less than the absorption edge of said selected element, said sample being excited by said first monochromatic X-ray beam to produce fluorescent characteristic radiation of other elements in said sample having an absorption edge wavelength which is greater than the wavelength of said first monochromatic X-ray beam and backscattered radiation of said first monochromatic X-ray beam and by said second monochromatic X-ray beam to produce fluorescent characteristic radiation of said selected element and said other elements and backscattered radiation of said second monochromatic X-ray beam;

means positioned adjacent to and on the same side of said sample as said irradiating means for detecting said fluorescent characteristic radiation and said backscattered radiation produced in response to said first and second monochromatic X-ray beams; and

means operatively coupled to said alternately irradiating means for adjusting the intensities of said monochromatic X-ray beams to substantially balance the intensities of said fluorescent characteristic radiation from said other elements and backscattered radiation received by said detecting means in response to each of said monochromatic X-ray beams irradiating said sample,

said detecting means being responsive to the difference in total radiation received in response to said sample alternately irradiated by said monochromatic X-ray beams to produce a modulated output signal the magnitude of which varies as a function of the radiation counts of fluorescent characteristic radiation received by said detecting means from said selected element.

**12.** The apparatus of claim **11** further comprising

filtering means positioned between said detecting means and said sample for selectively transmitting to said detecting means fluorescent characteristic radiation and backscattered radiation, said filtering means being selected to have an absorption edge wavelength which selectively transmits said selected element fluorescent characteristic radiation with minimum absorption and all other radiation with greater absorption.

**13.** The apparatus of claim **12** further including

means for alternately directing two polychromatic X-ray beams along separate predetermined paths;

first means including a first secondary emitter positioned along the predetermined path of one of said polychromatic X-ray beams to irradiate said first secondary emitter with said one polychromatic X-ray beam for producing said first monochromatic X-ray beam; and

second means including a second secondary emitter positioned along the predetermined path of the other of said polychromatic X-ray beams to irradiate said second secondary emitter with said other polychromatic X-ray beam for producing said second monochromatic X-ray beam.

**14.** The apparatus of claim **13** further comprising

a source for producing and directing an electron beam along a preselected path; and

an anode positioned along said preselected path and adapted to be bombarded by said electron beam for producing said two polychromatic X-ray beams.

**15.** A differential emission X-ray gauging apparatus for measuring concentration of a selected element in a first material coated on a second material substantially independent of variations in thickness of the second material, said apparatus comprising

first means for generating and directing a first monochromatic X-ray beam along a first predetermined path to irradiate said first material and said second material, said first monochromatic X-ray beam having a wavelength which is slightly greater than the absorption edge of said selected element exciting other elements in said first material and said second material having an atomic number less than that of said selected element to produce fluorescent characteristic radiation from said other elements and backscattered radiation of said first monochromatic X-ray beam;

second means for generating and directing a second monochromatic X-ray beam along a second predetermined path to irradiate said first material and said second material, said second monochromatic X-ray beam having a wavelength which is slightly less than the absorption edge of the selected element for exciting said selected element and said other elements to produce fluorescent characteristic radiation and backscattered radiation of said second monochromatic X-ray beam;

means operatively coupled to and adapted to control said first and second means for alternately irradiating said first material and said second material with said first and second monochromatic beams;

means opertaively coupled to said first means and said second means for adjusting the intensity of at least one of said monochromatic X-ray beams to balance the fluorescent characteristic radiation from other elements and said backscattered radiation produced in response to said at least one monochromatic X-ray bean with that produced in response to the other monochromatic X-ray beam; and

means positioned relative to said first material for detecting said fluorescent characteristic radiation emitted from said other elements and backscattered radiation when said first monochromatic X-ray beam irradiates said first material and said second material and fluorescent characteristic radiation rfom said selected element and said other element backscattered radiation when said second monochromatic X-ray beam irradiates said first material and said second material, said detecting means being responsive to the different between the total radiation produced in response to each of said first and second monochromatic X-ray beams to produce an output signal which represents the concentration of said selected element in said first material.

**16.** The apparatus of claim **15** further comprising

a filter selected to be a material having an absorption edge characteristic wavelength which is slightly greater than the characteristic radiation wavelength of said first monochromatic X-ray beam and which is slightly less than the characteristic radiation wavelength of said second monochromatic X-ray beam, said filter being positioned between said first material and said detecting means for selectively transmitting said selected element fluorescent characteristic radiation produced in response to said second monochromatic X-ray beam with minimum absorption and said other elements fluorescent characteristic radiations and said backscattered radiations with substantially greater absorption to increase the ratio of transmitted selected element fluorescent characteristic radiation to all other fluorescent characteristic radiation and backscattered radiations.

17. The apparatus of claim 16 wherein said selected element is silver having a concentration of less than about 10 mg./dm.$^2$ and said filter is selected to be silver.

18. A method for measuring concentration of a selected element on a target comprising the steps of

generating a first monochromatic X-ray beam having a wavelength which is slightly greater than the absorption edge of said selected element;

directing said first monochromatic X-ray beam along a first predetermined path to irradiate said target containing said selected element exciting other elements in said target having an absorption edge wavelength which is greater than the wavelength of said first monochromatic X-ray beam to emit fluorescent characteristic radiation and back-scattered radiation;

generating a second monochromatic X-ray beam having a wavelength which is slightly less than the absorption edge of said selected element;

directing said second monochromatic X-ray beam along a second predetermined path to irradiate said target at a period other than a period when said first monochromatic X-ray beam irradiates said target exciting said selected element and said other elements to emit fluorescent characteristic radiation and back-scattered radiation;

balancing the intensity of said first and second monochromatic X-ray beams so that said fluorescent characteristic radiation from said other elements and said back-scattered radiation are substantially the same for each monochromatic X-ray beam;

detecting, on the same side of said target as said first and second generating means, the difference between the total radiation emitted from said target in response to said first and said second monochromatic X-ray beams, respectively; and

producing in response to the difference in total radiation a modulated output signal representing concentration of said selected element.

19. The method of claim 18 further comprising the step of

filtering said radiation from said target by selectively transmitting said selected element fluorescent characteristic radiation with slight absorption and said other element fluorescent characteristic radiation with greater absorption to increase the ratio of intensity of said selected element fluorescent characteristic radiation to the intensity of said other element fluorescent characteristic radiation and back-scattered radiation before detecting of said radiation.

20. A method for measuring concentration of a selected element in a first material coated on a second material wherein the selected element differs by at least one atomic number from any other element in the first and second material comprising the steps of



generating and directing a first monochromatic X-ray beam along a first predetermined path to irradiate a localized area on said first material, said first monochromatic X-ray beam having a wavelength which is slightly greater than the absorption edge of the selected element producing characteristic radiation from other elements having an atomic number which is less than that of said selected element and back-scattered radiation;

generating and directing a second monochromatic X-ray beam which is balanced in intensity with respect to said first monochromatic X-ray beam along a second predetermined path to irradiate substantially said localized area during a period other than the period when said first monochromatic X-ray beam irradiates said area, said second monochromatic X-ray beam having a wavelength which is slightly less than the absorption edge of the selected element producing fluorescent characteristic radiation from said selected element and from said other elements of lower atomic number and back-scattered radiation;

detecting the fluorescent characteristic radiation emitted from said first and second materials in response to said first and second monochromatic X-ray beams; and

producing a modulated output signal having an amplitude the magnitude of which is proportional to the difference in total radiation received by said detecting means during the respective periods and represents the concentration of said selected element in said first material.

21. The method of claim 20 further comprising the step of

selectively filtering said radiation from said target with a filter comprising said selected element before detecting of said radiation.

22. The method of claim 21 wherein said selected element is silver.


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WILLIAM F. LINDQUIST, Primary Examiner

U.S. Cl. X.R.

250—99, 83.3; 313—56

# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,525,863 Dated August 25, 1970

Inventor(s) Nikiforos Constantine and Robert C. Hill

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, Line 23, after "a" insert --predetermined path to irradiate substantially the same--; Column 1, Line 24, delete "A detecting means positioned adjacent to and on the same"; Column 1, Line 40, change "mesuraing" to --measuring--. Column 4, Line 48, change "gaughing" to --gauging--. Column 5, Line 18, change "iis" to --is--; Column 5, Line 35, change "gaughing" to --gauging--; Column 5, Line 52, change "monocromatic" to --monochromatic--. Column 12, Line 70, change ".395" to --.385--. Column 14, Line 17, change "10-15" to --10-50--. Column 15, Line 53, change "response" to --responsive--. Column 18, Line 48, change "rfom" to --from--; Column 18, Line 52, change "different" to --difference--.

SIGNED AND
SEALED
NOV 17 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents

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